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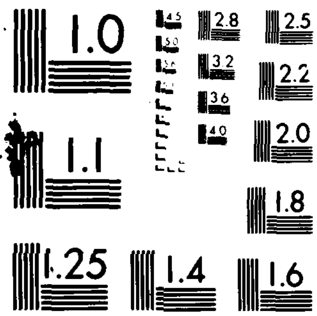

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Use of the Ocean for Man's Wastes

Engineering and Scientific Aspects

Proceedings of a Symposium

June 23-24, 1981
Lewes, Delaware

Marine Board

Assembly of Engineering

National Research Council

USE OF THE OCEAN FOR MAN'S WASTES: ENGINEERING AND SCIENTIFIC ASPECTS

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Convened by the Steering Committee on the Engineering Aspects of Using the Assimilative Capacity of the Oceans
for the
Marine Board
Assembly of Engineering
National Research Council

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STEERING COMMITTEE ON ENGINEERING ASPECTS OF USING THE ASSIMILATIVE CAPACITY OF THE OCEANS

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PREFACE

Use of the oceans for the disposal of waste generated from our increasingly urban and coastal society brings to bear in one issue those forces shaping national ocean policy for over 30 years. These forces include advancements in technology--in the knowledge of the nature of the sea and of systems to operate in it and on it, concern for the preservation of the environment which has emphasized the ecological well-being of our coastal waters, and the growth of government regulation that reflects the often contending pressures of development and preservation.

The improvement of ocean engineering capability which will be responsive to the balanced use of our coastal ocean resources has long been a priority interest of the Marine Board, beginning with an investigation of waste management concepts for the coastal zone in 1970. For over a decade, there has been an increasing requirement for disposal locations for municipal sewage sludge, industrial waste, and dredged material. At the same time, a series of public laws severely restricted the options available for disposal, first in the oceans, then by incineration, and finally by placement in or on the land.

There has been increasing pressure on federal and local governments to reassess the laws and regulations that have all but removed the option of using the ocean as a medium for disposing, and in some cases, assimilating man-generated waste. This situation has been highlighted by recent litigation between the city of New York and the Environmental Protection Agency regarding the dumping of sewage sludge on the New York Bight.

The Assembly of Engineering and the Marine Board have been sensitive to this increasing enigma which has become an issue of national concern. Early in 1981, the National Research Council appointed a steering committee under Marine Board auspices to plan and conduct a symposium "to provide an assessment of the state-of-knowledge fundamental to identifying and scoping the engineering problems involved in using the oceans as means of accepting and assimilating waste." This symposium was held June 23-24, 1981, at the University of Delaware's College of Marine Studies, Lewes, Delaware.

About 70 engineers, scientists, and persons responsible for the conduct of municipal and industrial waste management programs met for the two-day symposium to present, discuss, and review the scientific basis of understanding about waste disposal in the oceans. With this background, the various needs for using the ocean disposal alternative were identified. The engineering response to these needs, based on

scientific knowledge and experience was presented, and the regulatory response was then discussed by a panel of experts in waste management and environmental protection. A summary of observations concluded the symposium.

These proceedings constitute this publication. The opinions and recommendations contained herein are those of the participants and may not necessarily represent those of their organizations, the steering committee, the Marine Board, or the National Research Council.

The Marine Board wishes to acknowledge the assistance of Dr. William S. Gaither, Dean of the College of Marine Studies, University of Delaware, in making available the facilities of the Virden Center at Lewes, Delaware for this symposium.

SUMMARY

The sea is potentially an important receiver of wastes. The Marine Board, Assembly of Engineering, National Research Council, convened a symposium to explore the capacity of the oceans to assimilate wastes and the processes by which that capacity can be utilized. The symposium was held in Lewes, Delaware in June, 1981. The speakers at the symposium defined the major technical problems and engineering concerns involved in using the oceans to accept and assimilate waste. Speakers and panel participants recognized that there are many wastes--such as biodegradeable organic matter, and under certain circumstances, industrial wastes--that can be assimilated by the ocean. Moreover, they frequently expressed the view that the ocean option should be considered with land and air disposal in waste management assessments. The capability of the ocean is underused, in the view of the presenters, many of whom also emphasized that the ocean assimilative capacity can be exceeded and must be evaluated on a site-specific basis.

Dr. Edward Goldberg opened the symposium by identifying the need to know more about the ocean's limits for accepting waste and the research required to establish these limits. Dr. G. T. Csanady pointed out that recent research on coastal ocean circulation has yielded much quantitative knowledge of the coastal flow environment. However, for deep ocean sites, prediction by modeling of the fate of wastes can not now be realistically done due to great uncertainties about interior oceanic circulation and efficiency of the mixing processes. Even so, it was pointed out that we know more about the physical characteristics of the ocean than we know about the physical characteristics of groundwater.

In an overview of the biological basis of understanding, Dr. Donald Phelps noted that bulk of biological effects data for marine biota now available needs to be verified under field conditions. He observed there is a small, but growing data base to answer questions about the relative health and/or assimilative capacity of the coastal environments, and this base may be rapidly enlarged through application of some new biological effects monitoring techniques. Research investigation of the conservative limits of the use of biological sentinels, such as "the mussel watch," as a surrogate for other biological systems, was advocated by Dr. Phelps. The need for research in relevant biological effects--bacterial response and molecular genetics studies--was raised by several persons in presentations as well as in discussion.

Investigators of radioactive waste disposal in the ocean have provided a data base and tools for modeling and analysis which may be applied to the disposal of non-radioactive wastes in the sea.

Dr. Stephen Dexter reported on containment techniques and materials for radioactive waste disposal as an alternative to the ocean assimilation alternative for non-radioactive matter.

Monitoring technology and approaches were discussed by Dr. Lawrence Swanson who proposes an integrated national pollution monitoring system which would rely on existing compliance and monitoring activities and would be arranged in regional networks.

Dr. Swanson and several other participants noted that effective waste management requirements, which are as applicable to disposal in the ocean as to any other medium, are dependent on early identification of unacceptable pollutants, source control, and pretreatment. He also encouraged engineers to look at more effective ways to place waste into the marine environment. In particular, ship and barge disposal techniques should be examined and capping of contaminated dredge soil explored. The need for flexibility in waste management programs and regulations in order to take account of special regional considerations and new data and technology was emphasized by several participants.

Expertise in municipal waste management and planning, and in disposal of industrial fluids and dredged materials. Their messages commonly urged that equal consideration be given to all media (ocean, land, and atmosphere) as possible waste disposal options. It was acknowledged that comparisons between media will require improvement in risk analysis techniques and means of considering public perception and social interest. In regard to disposal of dredged materials, Dr. Robert E. Engler expressed the view that open-ocean disposal should be considered an acceptable method and be regarded as at least equal to land alternatives in planning considerations. He also noted that, from a technical viewpoint, serious considerations should be given to disposal of toxic dredged material in open-water in conjunction with appropriate site selection, capping, and long-term site management.

The County Sanitation District of Los Angeles County ocean disposal experience and future requirements of the (LACSD) were presented, including a review of economic costs and environmental benefits. Developments in this region are likely to influence the development of ocean waste disposal technology and also federal regulation.

Dr. Norman Brooks discussed an approach to designing an appropriate engineered system for disposing waste water and sewage sludge. He commented that use of the term "assimilative capacity" should not imply that up to a certain point everything is fine and beyond that point things are bad. Instead, it should be understood that any waste water discharge has some effects which depend on system design. In his view, these effects are less than with other possible engineering solutions of waste water disposal, such as on land or in inland waters.

Panel discussions on public law and regulatory modification raised several viewpoints regarding policy for managing toxic waste materials and whether to isolate and contain such waste or disperse it. Such a policy influences the alternative to use the ocean, which is primarily a dispersal medium. Questions regarding the difficulty of monitoring ocean disposal sites and the ability to localize ocean dumping were also raised in panel discussions. Dr. Davis Ford concluded the symposium with his observations of the major points made in presentations.

CONTENTS

THE CRYSTAL MOUNTAIN REPORT: AN APPROACH TO DEFINING OCEAN ASSIMILATIVE CAPACITY

by

Edward D. Goldberg*

Abstract

In 1979, seventy scientists deliberated at Crystal Mountain, Washington, upon the abilities of the U.S. coastal ocean to receive industrial, agricultural, and domestic wastes without unacceptable impacts upon marine resources. They reached an unqualified, if not unexpected, conclusion: *the waste capacity of U.S. coastal waters is not now fully used.* The group included physicists, chemists, biologists, and ecologists. Four sites where discharges of waste are taking place--the New York Bight, the Southern California Bight, Dump Site 106, and Puget Sound--were intensively studied. Models were developed that could assess any unacceptable impacts upon coastal systems through disturbance to indigenous organisms. The models were based upon conservative assumptions. Recognition was given to the inadequacy and frequent unavailability of key information. Lacunae in knowledge essential to the formulation of more adequate models were identified.

Participants were well aware that additional and intensive studies are necessary before their findings might be translated into public policy. First, the amounts and compositions of wastes generated by industry and by domestic activities are yet to be compiled. Such information is essential for a more extended use of the oceans for waste disposal. Some of the industrial data may be proprietary. Yet there may be strategies in which the information may be transferred from industry to scientists without jeopardizing the economic position of the involved companies. Of great importance is the systematic collection of waste generation data to enable the formulation of present needs and prediction of future ones for disposal. Essential information includes the amounts, forms, and compositions of the wastes. The compositional data may be expensive to obtain, depending upon the number of substances sought. Every effort should be made to reduce the demand for compositional data.

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Secondly, participants recognized that their findings could be used effectively only in a comparative sense. For any given waste at any given location, consideration must be given to optional forms of disposal to land or to the atmosphere through combustion, where possible. Here not only scientific criteria are required but also those from economics, engineering, and political science. Cost-benefit and risk analyses of waste disposal in coastal ocean and inland sites have been carried out in only a few cases by interdisciplinary groups. These evaluations are especially important in discussions with those environmentalists who have a priori reservations about discharging anything anywhere in the marine system.

There is a very distinct yin-yang relationship between pollution problems and those of the utilization of one of the resources of the ocean, waste space. Problems may arise in conflicting uses of the marine environment, especially where utilization of one resource jeopardizes the use of another. The resources include fisheries, recreation, transportation, minerals, vistas, ocean esthetics, and the ocean's use as a heat sink, energy source, and waste space.

A classic case of conflict between minerals and fisheries is occurring in the North Sea where the recovery of sand and gravel for the sea floor interferes with the existence of nursery and breeding grounds for fish. The options then are to restrict the recovery of these minerals to protect the fisheries or perhaps to sacrifice the fisheries to mine the minerals.

In our use of the ocean, we attempt to predict to what extent a specific area of the ocean can be loaded with wastes without disturbing the integrity of its ecosystem. This interest differs from that of many pollution problems in which public health is the main concern.

Let me first note that coastal oceans and open oceans may already be suffering disturbances because of the entry of a large number of polluting substances. The types of pollutants that can interfere with the integrity of ecosystems have already been identified at the Estes Park Workshop.* (See Table 1.) Many of these are being monitored in coastal waters for their levels.

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*Estes Park (Colorado) Workshop on Scientific Problems Relating to Ocean Pollution, July, 1978.

Table 1

The Collectives of Pollutants in the Oceans

Synthetic Organics
Chlorination Products
Dredged Spoils and Large Volume Waste
Litter
Artificial Radionuclides
Microorganisms
Trace Metals
Fossil Fuel Compounds
Biostimulants

We still have crucial problems that need evaluation by the scientific community. For instance, the toxaphene problem is not being addressed in a systematic way by any group of scientists in the United States today, yet this pollutant may be creating a serious environmental situation.

Toxaphene is being produced today at nearly the same annual rate as that of DDT in the late 1960s: 100,000 tons per year. Toxaphene is a group of slightly under 200 compounds, chlorinated hydrocarbons produced by chlorination, under ultraviolet light, of wood waste products, camphors. Unlike DDT, this group of compounds--the toxaphenes--contains carcinogenic and mutagenic members. They may be more persistent in the environment than DDT and its degradation products. They are being used extensively to control pests that attack cotton and certain vegetables. Unlike DDT, toxaphene is not broken down by ultraviolet light. The toxaphene problem will probably be presented by my Swedish colleagues to the 1982 Conference on the Environment in Stockholm. It is one of these gaps in knowledge that we must fill before we can concern ourselves with the problems of using oceans as disposal sites for wastes. We have identified these collectives of pollutants, but tragically we are not directing enough scientific attention to them. They comprise a group of background pollutants that may affect the ability of some water bodies to accept wastes.

Now, with this stepping stone of having identified the pollutants, some understanding of how they affect ecosystems is needed. This leads to a definition of assimilative capacity: the amount of material introduced to a water body per unit time that can be contained within it without producing an unacceptable impact upon living or nonliving resources. Primarily we are concerned with living resources. The maximum acceptable amount becomes evident at an "end point" when an unacceptable change in the characteristics of the marine environment occurs. At this end point, the addition of more material produces an unacceptable condition.

Many examples may be found in the husbandry of artificial radionuclides which enter the coastal environment. Cesium 134 and 137 are radioactive nuclides introduced to the Irish Sea from the reprocessing plant at Windscale operated by British Nuclear Fuels, Limited. These two radioactive species enter the marine food chain and eventually become incorporated in commerical fish.

The maximum acceptable amounts of cesium 134 and 137 which can be introduced to the Irish Sea are determined by the eating of fish by a critical population, the heaviest consumers. This group usually includes fishermen, some of whom consume about 300 grams per day of their product.

In 1970, this critical population consumed up to 26 percent of the maximum acceptable dose of these nuclides, as defined by the International Commission on Radiological Protection. This amount was considered acceptable by the British scientific community. The end point, of course, would be the consumption of 100 percent of a maximum acceptable dose by members of the critical population. Nearly all endpoints so far formulated involve the protection of human beings.

The Crystal Mountain Workshop proposed endpoints for waste disposal based both on public health and the integrity of ecosystems.

In Puget Sound, some evidence suggests there is an increased incidence of red tides that might be related to the discharge of sewage from a waste disposal plant. There is also some indication that this disposal induced a mortality of oyster larvae. These provide suggestions that endpoints may have been passed. But these findings need assessment, and they were the only examples indicating that the assimilative capacity of Puget Sound might have been exceeded.

In New York Bight, there was the problem of cadmium in oysters. A model was formulated that indicated that, if oysters live on dredge spoils that contain high amounts of cadmium, and if they were consumed by persons that eat 100 or so grams per day, these people might be made nauseous. Again, we have a sense of proposing an endpoint for waste disposal.

But the overall conclusion of the meeting is most important--that the waste capacity of U.S. coastal waters is underused. It was reached using the prevailing wisdom of the day. In addition, research needs were identified. (See Table 2.) We need to know more about the toxicity of pollutants to marine organisms, especially stresses determined by field measurements. This need will be addressed in several subsequent presentations today.

Table 2

Research Needs

- Compilation of present and predicted future waste fluxes from industry, agriculture, and society.
- Development of engineering protocols for utilization of assimilative capacity concept.
- Field indicators of biological impact.
- Synergistic impacts of pollutants. The multiple impact concept.
- Studies of land versus marine disposal based upon scientific, economic, and social considerations.

Perhaps the most important problem in marine pollution today that relates to the assimilative capacity is the continuing trend toward eutrophication of coastal waters. This was emphasized by Herb Curl of the National Oceanic and Atmospheric Administration's Laboratory in Seattle at the Estes Park Workshop in 1978.

The oceans are receiving increased inputs of nutrients via the rivers. During the past 30 years, nutrient concentrations in rivers, on a global basis, have increased markedly. It appears that nitrogen levels are increasing by about a factor of 15 and those of phosphorus by a factor of five. This situation is a consequence of the widespread use of fertilizers, detergents, and industrial chemicals. On top of this is an increased flux of organic compounds from deforestation, land-use changes, etc., in many regions. The trend toward eutrophication has been observed in many places such as those listed below. They are just a few examples from all over the world that are documented in the Estes Park Report.

Chesapeake Bay
New York Bight
Southern California Bight
Baltic Sea
Adriatic Sea
Aegean Sea
Oslo Fjord
Kaneohoe Bay, Hawaii
Lake Erie
Tokyo Bay

The problem is modeled in Figure 1. We have increasing fluxes of carbon, nitrogen, phosphorus, and sulfur (CNP's) to rivers and to the oceans. This influx initially causes an increased production of organic matter. This is followed by a displacement of diatoms by brown and blue-green algae. The diatoms are the base of the food chain for many commercial fish and shellfish, which may gradually be

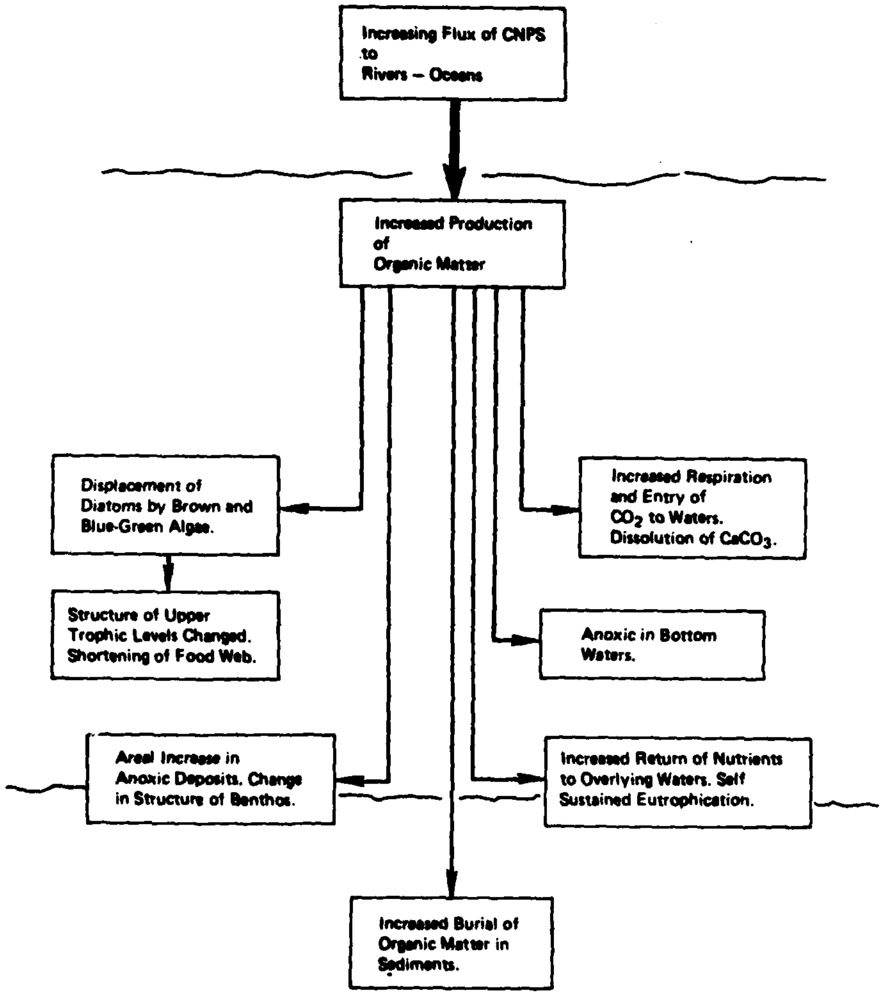
Increasing Flux of CNPS to Rivers – Oceans
Increased Production of Organic Matter
Displacement of Diatoms by Brown and Blue-Green Algae.
Structure of Upper Trophic Levels Changed. Shortening of Food Web.
Increased Respiration and Entry of CO_2 to Waters. Dissolution of $CaCO_3$.
Anoxic in Bottom Waters.
Areal Increase in Anoxic Deposits. Change in Structure of Benthos.
Increased Return of Nutrients to Overlying Waters. Self Sustained Eutrophication.
Increased Burial of Organic Matter in Sediments.

Figure 1

disappearing. The loss of diatoms changes the makeup of the upper trophic levels and, of course, shortens the food web. Another possible consequence is the increased respiration of CO_2 to the water, caused by the burn-up of the larger amounts of organic matter. This has not been documented yet. There may also be a dissolution of calcium carbonate in the coastal zone as a consequence of this increased respiration.

Because of the fallout of organic matter, we are witnessing anoxia in the bottom waters. We are also seeing an increased areal extent of anoxic deposits. Futhermore, a change in the structure of the benthos may be occurring.

There is an interesting ramification of this situation. This increased amount of organic matter is oxidized in the sediments resulting in an increased return of nutrients to the overlying waters by diffusion. The nutrients' return, coupled with the increased flux of nutrients, may produce a self-sustained eutrophication system. Finally, we have an increased burial of organic matter in the sediments.

Thus, I submit that one of the major problems in marine pollution science is this trend toward eutrophication, which is not being investigated systematically by any organization, university, government, or industry in the United States. This phenomenon may conflict with our more extensive use of the oceans as waste space.

Let me summarize my concerns. One of the prime deficiencies in the Crystal Mountain Report is the enumeration of the source function for the waste that might potentially be placed in the marine environment. What are the amounts of waste being generated per day by industry, society, and agriculture? What is the composition of these wastes? What are the geographical locations of the generation? What is their disposition today? Do we have a better place to put them? Some of the information may be proprietary, but I think we have to continue to ask how can we get the information, which is crucial and essential to the assimilative capacity concept and to the use of the oceans as waste space in the future.

Second, we have a great deal of work yet to do in defining what are acceptable end points. We clearly have to know much more about biological impacts.

Finally, although I think it is very rewarding that the engineers are now going to join the scientists in looking at this concept, we need to bring in the economists and social scientists to factor in their information on economics and risk analysis.

At the meeting on Crystal Mountain, we defined the assimilative capacity concept on the basis of a "look-see" by 70 scientists. The concept is still primitive. It is merely a springboard for future evaluation of the use of the oceans as waste space.

Thank you.

DISCUSSION

MEEKER: Dr. Goldberg, you referred at an earlier time to the idea of an acceptable dose. Does it signify a level at which no health effects can be found, or just what is the meaning of that idea?

GOLDBERG: Clearly, an alteration of the environment by the introduction of waste is going to cause an impact. When does it become unacceptable? Sometimes this is a subjective judgment. Let me give you an example. At the present time in regions of the Southern California Bight, 5 percent of the Dover sole, a noncommercial fish, have fin rot. Is this acceptable or not? You are not destroying the fin fish. Perhaps some of my environmental colleagues will say it is unacceptable to even destroy 0.1 percent. The benefit, of course, is the accommodation of the wastes in the Southern California Bight from about 11 million people.

Let me just cite another example. This is the case of the radioactive cesium ingestion by the British fish eaters who consume close to 26 percent of the acceptable dose.

The International Commission on Radiological Protection, on the basis of conventional wisdom, defines a maximum body burden of radioactive cesium that will produce no evident deleterious effects over the lifetime of the individual. This is how the assimilative capacity of the Irish Sea for radioactive cesium was determined. This is a much more objective approach to assimilative capacity than is an attempt to evaluate the acceptability of 5 percent of the Dover sole with fin rot.

Sometimes the endpoint is subjective, and sometimes it is objective.

BROOKS: You did not say anything about the removal of nutrients by harvesting of kelp and fish. I thought the problem was that we were short of nutrients in the shelf waters.

GOLDBERG: No, I am unaware of evidence to support this argument. In certain areas it may be that we are over harvesting such that we can not maintain a sustainable yield of product. With respect to the general situation, the trend is toward eutrophication--too much organic productivity on a global basis in coastal waters.

BROOKS: We like areas of upwelling that are used for fishing.

GOLDBERG: Upwelling is a desirable situation to that extent where the sediments do not become eutrophic and point where the diatoms are still the prevailing algae during most of the year.

ENGLER: Will a measure of "unacceptable" include social and economic impacts also? Or will it just be limited to the biological and chemical impacts?

GOLDBERG: You have to factor these parameters into your model. You have to factor in the economic cost of disposal. If you are going to compare land versus sea disposal, you have to consider the social problems also. One of the problems with radioactive waste disposal in the U.S. involves the social implications. No state wants nuclear wastes on its territory.

HIRSCH: I did not understand the comment about shortening the food web as a result of displacing diatoms.

GOLDBERG: This is the argument that is made in the Estes Park Report. It is argued by the biologists--and I am not a biologist--that, by changing the population from diatoms to flagellates and blue-greens, the flagellates are less acceptable as food. Some trophic levels just disappear because there is not sufficient food.

BROOKS: You talk about assimilative capacity. Do you think of it as a quantity or as a flux?

GOLDBERG: I think it has to be a flux. It has to be the amount that you can introduce per unit time that can be accommodated by a given volume of water.

TRANSPORT AND DISPERSION OF WASTE IN THE OCEAN

by

G. T. Csanady*

Abstract

A variety of oceanic processes--biological, chemical, and physical--convert objectionable components of waste ("pollutants") into harmless end products. From the point of view of waste dispersion all such processes may be regarded as distributed sinks, their intensity determining the oceanic lifetime of pollutants. The lifetimes of pollutants of prime current concern (petroleum and heavy metals, certain stable organic compounds, radioactive elements) range from a few days to centuries.

Most of these pollutants are not passive, in the sense of moving with ocean currents and mixing as seawater, but tend to reside in the particulate substratum of the ocean. Owing to chemical and biological interactions between the particulate substratum, the water column, and the sediments, pollutants are often recycled, so that distributed sources, as well as sinks, come to complicate the dispersal problem. The precise fate of various chemical species that behave in this manner is now in the forefront of research.

Floating pollutants and those that temporarily deposit at the sea floor, before being reentrained by a turbulence episode, disperse in a two- rather than a three-dimensional medium. They also are subject to reaccumulation in convergences. Existing knowledge of such two-dimensional dispersion processes is minimal.

Although the particulate substratum does not move entirely as seawater, primarily because of important relative vertical displacements, most horizontal motion is due to oceanic currents, in the case of either liquid or particulate pollutants. Ocean currents vary irregularly, mixing episodes occur sporadically, and the end result for pollutant particles which do not float or deposit is, effectively, three-dimensional random motion in the ocean interior.

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Pollution prediction models, verified by field experience, are available today only for short-lived pollutants (lifetime of the order of a day). For the longer-lived chemical species, mentioned earlier, probabilistic models are needed, predicting such quantities as the probability of exceeding threshold concentrations at given points in space. It is not clear, however, what specific index will prove most practical for each class of pollutant.

A key difficulty in modeling the fate of long-lived wastes is poor factual knowledge or understanding of oceanic circulation and of mixing processes in much of the ocean. Recent research on coastal ocean circulation has yielded much insight and quantitative knowledge of the coastal flow environment, so that engineering pollution prediction models for at least some well-explored shallow seas should now be feasible. The engineering science of this modeling has not, however, developed so far beyond an initial phase prediction capacity (plume models).

For deep ocean sites, the prediction of the fate of waste (in physical terms, meaning only advection and mixing) is not, at present, a realistic possiblity, owing to great uncertainties about the interior oceanic circulation and the efficiency of any mixing processes.

Introduction

The ocean may be said to possess an assimilative capacity for those wastes which are transformed by natural processes into neutral end products that do not pose a threat of nuisance or hazard. The transformations in question are generally chemical or biological in nature, rarely physical such as the permanent incorporation of materials into immobile sediment. Regardless of the details, from a physical point of view, all such transformations may be thought of as waste sinks, distributed in some manner over the water column or over the seabed. Given the existence of sinks, a quantity of some waste species with some potential for posing nuisance or hazard (a pollutant) eventually disappears following discharge into the ocean. Before this happens, however, the pollutant may endanger human health, damage living resources of the sea, or cause a highly negative aesthetic impact. The engineering challenge of marine waste disposal lies in the avoidance of such undesirable side effects.

One key aspect of waste behavior in the ocean is governed by the efficiency of sinks. Bacteria die off in about a day, while some radioactive species have a half life of the order of centuries. Within a short period, ocean currents and eddies can transport a waste cloud only so far from its point of introduction: a cloud of sewage bacteria moves, at most, some tens of kilometers before its virtually complete

disappearance. On the other hand, a pollutant with a lifetime of a century or two becomes mixed over the world ocean before eventually disappearing.

Undesirable effects of wastes released into the ocean are found to be a function of concentration, the amount of pollutant present per unit volume of seawater. A threshold concentration may often be defined below which there is no hazard or nuisance. At higher concentrations the effects may also depend on exposure time and conceivably on other variables, such as water temperature, the presence of another pollutant, and so on. To assess the side effects of some waste disposal operation, therefore, requires an estimate of the probability of higher than threshold pollutant concentrations affecting locations of interest (e.g., a bathing beach) or of joint probabilities of pollutant concentrations and exposure time, water temperature, or whatever. Any calculation, however simplistic or crude, leading to such estimates may be thought of as a model of pollutant behavior. Models are constructed on the basis of what is known of ocean currents and eddies, which not only transport the waste away from its point of introduction, but also dilute it (decrease its concentration) by mixing it with ambient seawater. The construction of reliable pollutant behavior models is an important task of environmental engineering science, a relatively new field of activity of the professional engineer.

The present state of the art in constructing oceanic pollutant behavior models is, very roughly, that reasonable predictions can be made of the dispersion of short lifetime (one day) pollutants such as bacteria in municipal sewage, released within a few kilometers of a coast.[1] In such applications, pollutant concentration is effectively controlled by the method of release (e.g., through multiport diffusers) and far-field or cumulative long-term effects are of no concern. However, when it comes to the fate of a pollutant of much longer lifetime, only very crude predictions can be made. This is true for several reasons. First, the intellectual framework is lacking. It is not clear what variables are best used as indicators of hazard or nuisance, what idealizations should be made in forecasting pollutant behavior, or how to reduce the complexity of the natural environment to a manageable set of parameters. Second, the scientific basis of pollutant behavior models is incomplete. The climatology of currents and the variable hydrography of any given region of the ocean is known at best in a sketchy way. Even the basic physics of oceanic currents and mixing processes is incompletely understood. This is especially true of the deep ocean, notably of the benthic boundary layer.

The knowledge of coastal ocean physics has advanced dramatically in recent years. But syntheses of this new knowledge and literature accessible to the nonspecialist are only now beginning to appear. However, even if ocean currents and mixing processes affecting

seawater were perfectly known, this would be inadequate, because most long-lived pollutants of importance preferentially attach themselves to particles.

The ocean contains a very large number of particles, mostly of biological origin, which, in the aggregate, may be thought of as a particulate substratum. Many complex transformations take place in this substratum: chemical reactions, upward movements of live organisms, settling of detritus, reentrainment from the seabed, etc. The net result is that pollutants may be recycled, i.e., some distributed sources may be present in addition to any sinks.

The objective of the present paper is to illuminate the above propositions further by discussing present knowledge relating to the physical aspects of pollutant behavior in the ocean, and how that behavior may eventually be modeled for the purposes of hazard or nuisance assessment associated with wastes of relatively long lifetime.

Physical Aspects of Waste Behavior

Pollutant lifetimes much longer than one day may be thought of in steps of a factor of ten as roughly 10 days, 3 months, 3 years, 30 years, 300 years and so on. Near the lower end of this scale are the lighter petroleum fractions which float and weather fairly rapidly, at the upper end radioactive man-made elements such as plutonium. Intermediate lifetime pollutants are, for example, persistent organic compounds such as DDT or polychlorinated biphenols (PCB's) or heavy natural metals such as lead or mercury.

The problem of the oceanic assimilation of wastes would be relatively simple if all pollutants just wandered around with ocean currents and mixed with other water masses as seawater. The vast three-dimensional space of the world ocean is available for the ultimate dispersal of such entirely passive pollutants. A number of diffusion experiments have been carried out with similar passive tracers. These experiments have elucidated important aspects of the initial (first three days or so) dilution problem.[2, 3] Over the much longer time scale of a decade, recent work on the oceanic mixing of tritium, derived from atomic bomb tests, has provided much new insight.[4, 5] Classical oceanographic work on the formation and worldwide distribution of water masses provides further clues on mixing over even longer time scales, perhaps centuries.[6] There exists, therefore, a reasonable foundation for assessing quantitatively at least the asymptotic behavior of passive pollutants in a general way.

One should hasten to add that much uncertainty remains even regarding the fate of passive pollutants when it comes to specific locations, especially on time-scales of the order of a few months. Ocean currents vary irregularly and their climatology is not known in

any detail except in a very few locations, the exceptions occurring mostly in the coastal ocean, i.e., over continental shelves, in enclosed shallow seas, etc. Figure 1 illustrates the trajectories of surface drogues traced acoustically in a recent experiment in the deep North Atlantic.[7] A "spaghetti" diagram such as Figure 1 could be used to estimate probabilities of a water particle moving from a pollutant source to some specific region of the ocean, or to calculate the long-term concentration for continuous release from a source. However, a direct observational basis is absent for most locations in the ocean for such estimates. (Existing knowledge on ocean currents and passive mixing processes is discussed further in the next section.)

One important class of pollutants departs from passive behavior owing to its buoyancy. Examples are light petroleum fractions or flotsam in municipal waste immiscible in seawater. A miscible liquid pollutant, even if buoyant prior to discharge, is soon diluted to the point where its buoyancy is not a factor in long-term dispersal. Permanently buoyant pollutants are dispersed over the two-dimensional medium of the sea surface, an intrinsically less effective process for their dilution than three-dimensional transport and mixing. Furthermore, oceanic observations on clusters of floats have shown that, instead of dispersing, a cluster may well reconcentrate in a convergence zone. At first sight this would seem to flout the second law of thermodynamics, but, of course, there is nothing mysterious about it. The "Maxwell's demon" is the buoyancy of floats, which prevents them from partaking in the downward movement of water in a convergence. As the water disappears between the floats, they come closer together.

Severe pollution problems may be caused by flotsam washing up on beaches. Because convergences near a coast are abundant, flotsam tends to arrive in concentrated batches, affecting some sections of a beach with especial intensity. Similarly, the impact of an oil spill on a coast is generally selective, and particularly distressing over short, intensely fumigated sectors. Observational or theoretical work on the dispersion, and especially on the beach deposition of flotsam has so far been minimal.

Although pollutants of positive buoyancy are a headache, they are overshadowed in importance by the vast population of small, mostly organic, particles in the ocean with slight negative buoyancy. This particulate substratum of the ocean forms the basis of marine life and is actively involved in biological processes such as birth, death, feeding, or excretion as well as in active chemical changes, oxidation, reduction, uptake of nutrients, and absorption or release of a variety of substances. The particle population, in consequence, is far from stable. Coalescence, breakup, growth, or shrinkage of individual particles are common. The chemically active nature of the particles has the very important practical effect that most pollutants, even

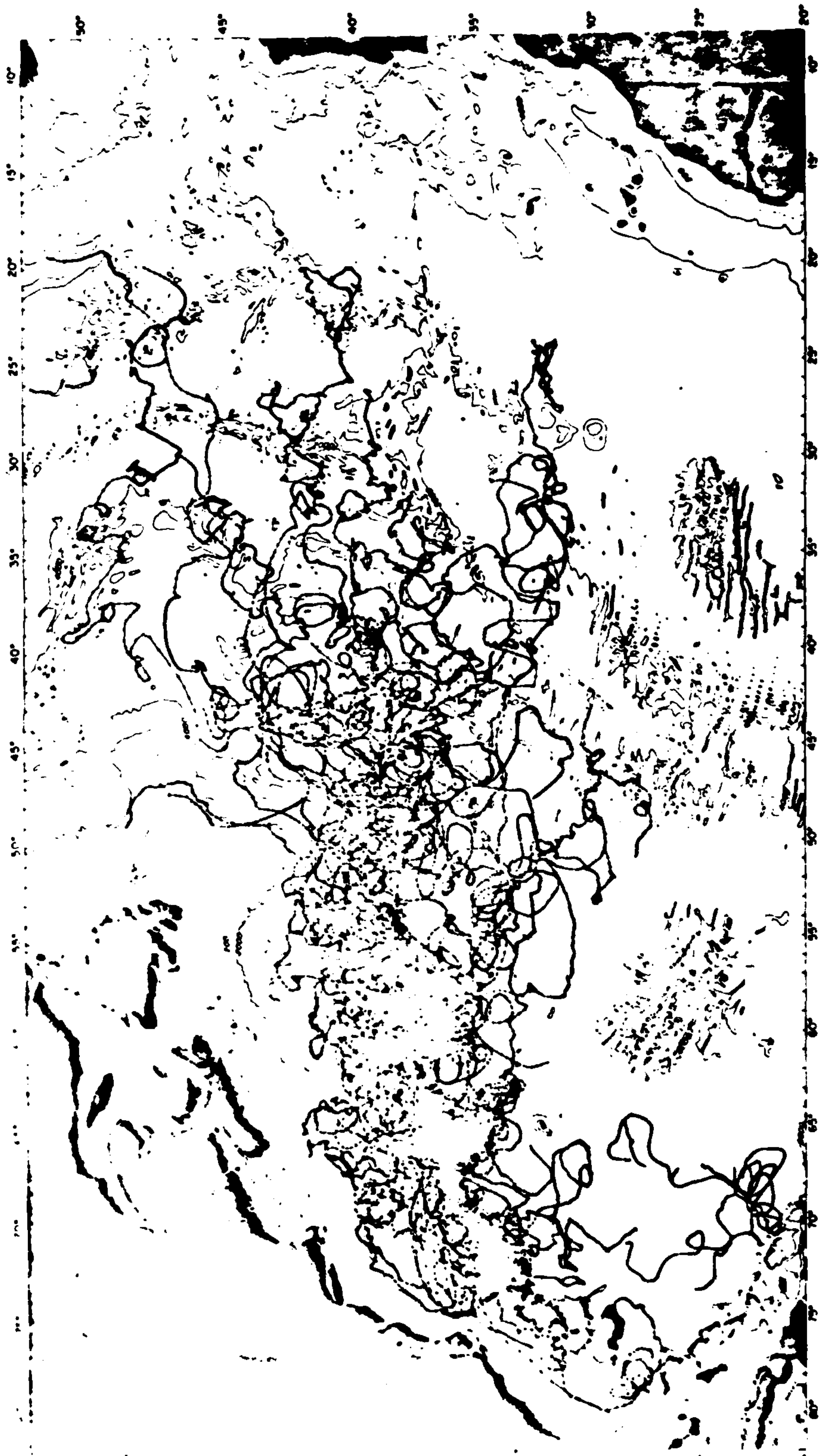

Figure 1. Trajectories of Surface Drogues in the North Atlantic

chemically stable components, tend to attach themselves to particles rather than to remain in the water column. This includes especially heavy metals and the difficult organic substances such as DDT or PCB's.

Once within the particulate substratum of the ocean, pollutants do not simply travel with ocean currents of mix as seawater, but settle at a slow rate (owing to the negative buoyancy of whatever particle they are associated with), are taken upward by living organisms, or deposit on the seafloor. Once on the seafloor, a pollutant may reenter the water column by physical reentrainment of particles through near-bottom turbulence, or as a result of chemical reactions within the sediment. In the former case, the succession of temporary deposition followed by travel with ocean currents leads to a random hop-scotch movement of particles along the seafloor. Over the long term, this is again a two-dimensional random walk process and has, in principle, many similarities to the surface travel of flotsam. Presumably, bottom hop-scotching particles accumulate in convergent zones where the water moves upward. In quiescent zones, where bottom turbulence is mostly absent, such particles presumably accumulate on the bottom and eventually become part of the permanent sediment. However, chemical reactions within the sediment may still release pollutants back into the water column, constituting a local source (rather than sink) for such pollutants.

The complexity of processes in the particulate substratum of the ocean is considerable and subject to vigorous current research. From the point of view of physics, one may note that pollutants that enter the substratum do not simply travel with ocean currents, but are subject to particle movements relative to the water column, especially in the vertical direction. Thus such pollutants may cross a sharp pycnocline (interface between heavier and lighter layers of seawater) at a much higher rate than passive water particles, which mix across such interfaces very slowly owing to gravitational stability. Furthermore, there are complex exchange processes between the water column and sediment, which depend, in an important way, on bottom turbulence.

Transport and Mixing in the Ocean

While the dispersion of particles in the ocean is a more complex process than the dispersion of dissolved substances, both processes are the result of transport by oceanic currents and of mixing events. Except in a few locations, adding up to no more than a few percent of the total space occupied by it, the world ocean is generally density-stratified, strong enough for the force of gravity to suppress turbulence. Therefore layers of the ocean of slightly different density slide over one another without much friction or mixing. Water masses of different origin may be distinguished by very small differences in temperature, salinity, oxygen, silicate content, or in the concentration of other dissolved substances, because these differences

remain conserved for long periods. In this manner, oceanographers have for many years been able to chart the movement of water masses over distances of global scale--for example, the spread of bottom water of Antarctic origin northward first into the South Atlantic and then into the North Atlantic or the westward movement of saline mediterranean water along intermediate layers of the Atlantic (Figure 2). More recently, tritium derived from atom bomb tests has provided oceanographers with an opportunity to trace the movement of surface waters of midlatitudes, as these dive under lighter layers of the subtropical gyres and move equatorward.[8]

Where mixing of immediately overlying layers does take place in the ocean, it is due to one of three processes:

Sporadic turbulence in the ocean interior, where stability breaks down locally due to strong shear. This is akin to clear air turbulence in the atmosphere sometimes perceived by travelers in jet aircraft.

Mechanical turbulence due to boundary shear, found mainly in the bottom (benthic) boundary layer and especially in the shallow coastal ocean where tidal currents are strong.

Convective turbulence due to surface cooling or to the freezing of water and consequent release of salt. This occurs mostly in high-latitude oceans on a seasonal cycle and is the primary cause of mixing, or "water mass formation" as oceanographers call it, on a worldwide basis.

The actual motions of the overlying oceanic layers are complex and may be thought of as a superposition of motions on a variety of time-scales. In the coastal ocean (less than 100 meters or so in depth) tidal- and wind-driven motions dominate, with typical periods of a half-day and four days respectively. The surface layers of the deep ocean are also wind-driven, but deeper layers move mainly in response to pressure forces arising from a piling up of water against continental coasts or from the integrated effect of buoyancy forces, as slightly lighter or heavier waters occupy different horizontal locations. In addition, there are wavelike motions of many kinds, from surface waves, through inertial oscillations associated with the earth's rotation, fast and slow internal waves involving large vertical movements of constant density surfaces, to vorticity waves of global scale similar to waves in the atmospheric jet stream.

A superposition of all these component motions, given their incommensurable frequencies, leads to a time history of currents at a fixed point which is to all intents and purposes random. Similarly, particle displacements may be described as continuous random movements,

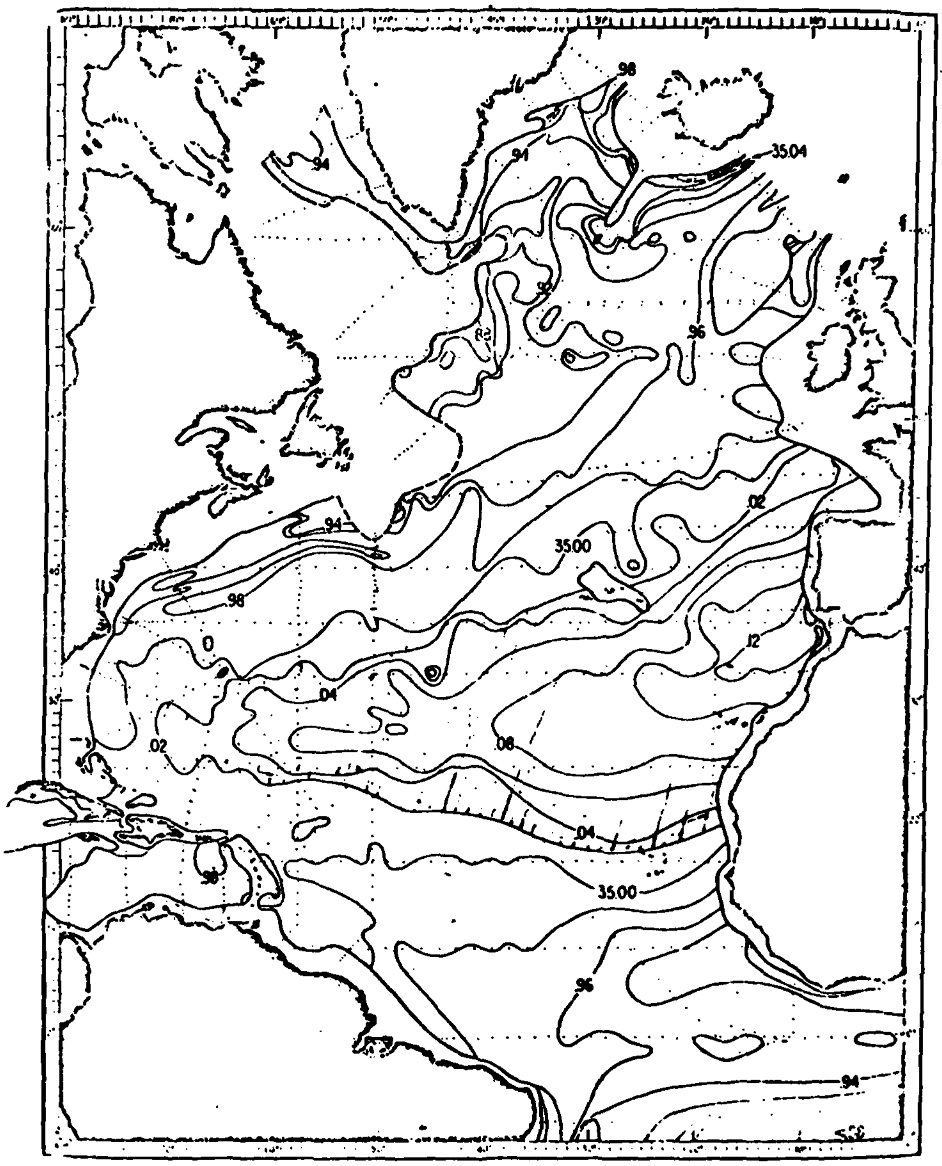

Figure 2. Salinity (parts per thousand) at the
4.0°C Potential Temperature Surface

as was illustrated in Figure 1. This does not, of course, exclude the possibility of a mean motion, or of the prominence of one or two wave-like components of motion. In the coastal ocean, for example, tidal or inertial motions are often conspicuous, as is usually a mean flow along constant depth contours (isobaths).

The spatial patterns of the longer-term mean motions often show a fascinating complexity. As an example, consider the narrow band of deep water separating the Gulf Stream north of Cape Hatteras from the North American continental shelf. This is referred to as "slope water," because it lies over the continental slope. In the horizontal plane, the dominant long-term circulation of the slope water is a counterclockwise, or cyclonic gyre (Figure 3). The slope-stream leg of this gyre closer to land is presumably driven by buoyancy forces, through the accumulation of low-salinity water at the coast due to ice melt and river runoff. The offshore leg is effectively part of the Gulf Stream system, which is indirectly driven by the oceanwide wind stress pattern, through an accumulation of warm (light) water near the ocean's western boundary. In a cross-isobath transect (Figure 4) the surface layers of slope water move seaward, an intermediate layer, centered at about 150 meters depth, landward. There is also strong divergence in the surface layers, causing a slow vertical upward migration of slope water especially just seaward of the edge of the continental shelf. Also notable is a zone of strong horizontal property gradients and sloping constant density surfaces near the shelf edge (frontal zone). Shelf water lying landward of the frontal zone sometimes crosses seaward in large boluses moving at the surface or at a shallow depth, while slope water forms boluses at the bottom moving onto the shelf. Similar boluses of Sargasso Sea water released landward by the Gulf Stream are especially large and are known as warm-core Gulf Stream rings. The transverse circulation in slope water, the bolus separation process and the slope-stream cyclonic gyre, together, constitute a particularly effective flushing device for the populous North American east coast. Intuitively, it is clear that this is a fortunate situation for the assimilative capacity of this part of the ocean. The important engineering task is to assess that assimilative capacity quantitatively, a task that requires one to face the problem of modeling.

A Hierarchy of Pollution Prediction Models

One of the most difficult decisions in the assessment of pollution effects is the choice of a suitable index of nuisance or hazard. In air pollution modeling it is commonly taken for granted that the concentration of a given gas in the unit-mass of air is a satisfactory index, even though damage to vegetation by sulfur dioxide, for example, also depends on exposure time and on a host of properties of the target species, including sensitivity which varies with season or even with the time of day. A similar index frequently used in water-quality

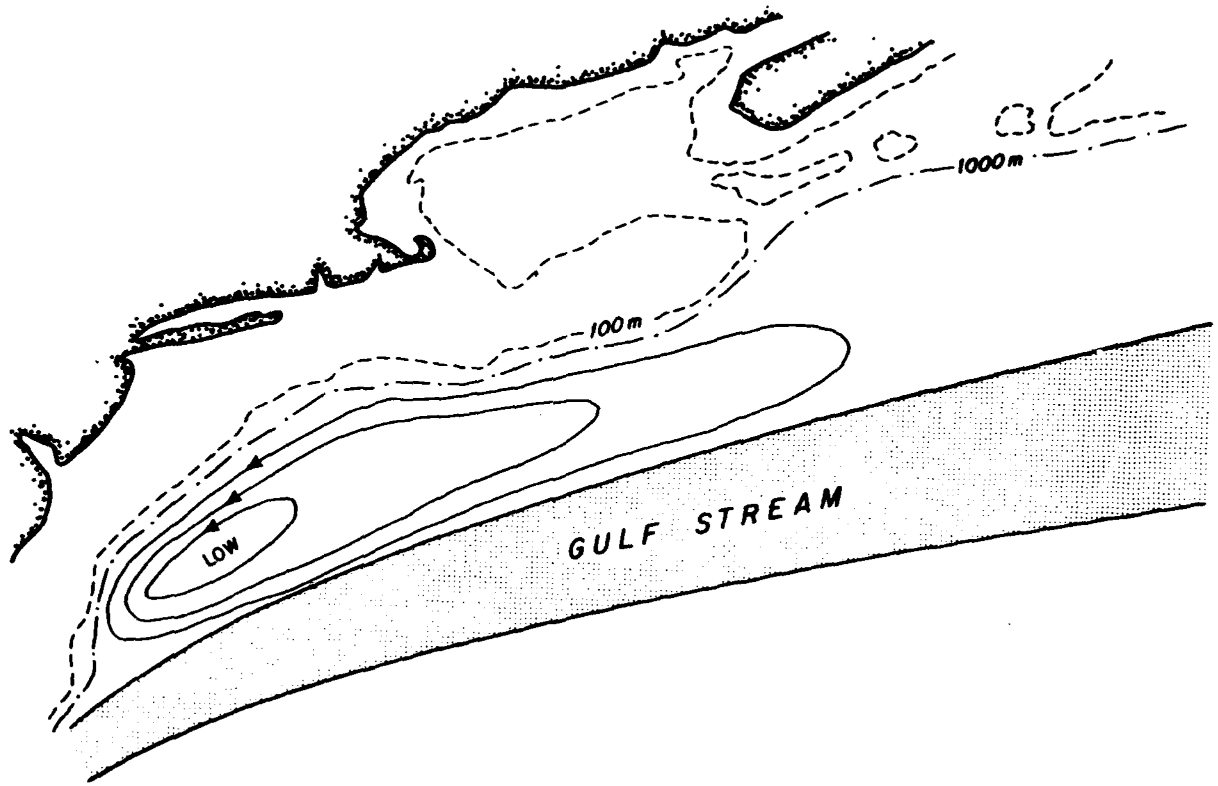

Figure 3. Gulf Stream and Slope Water Circulation

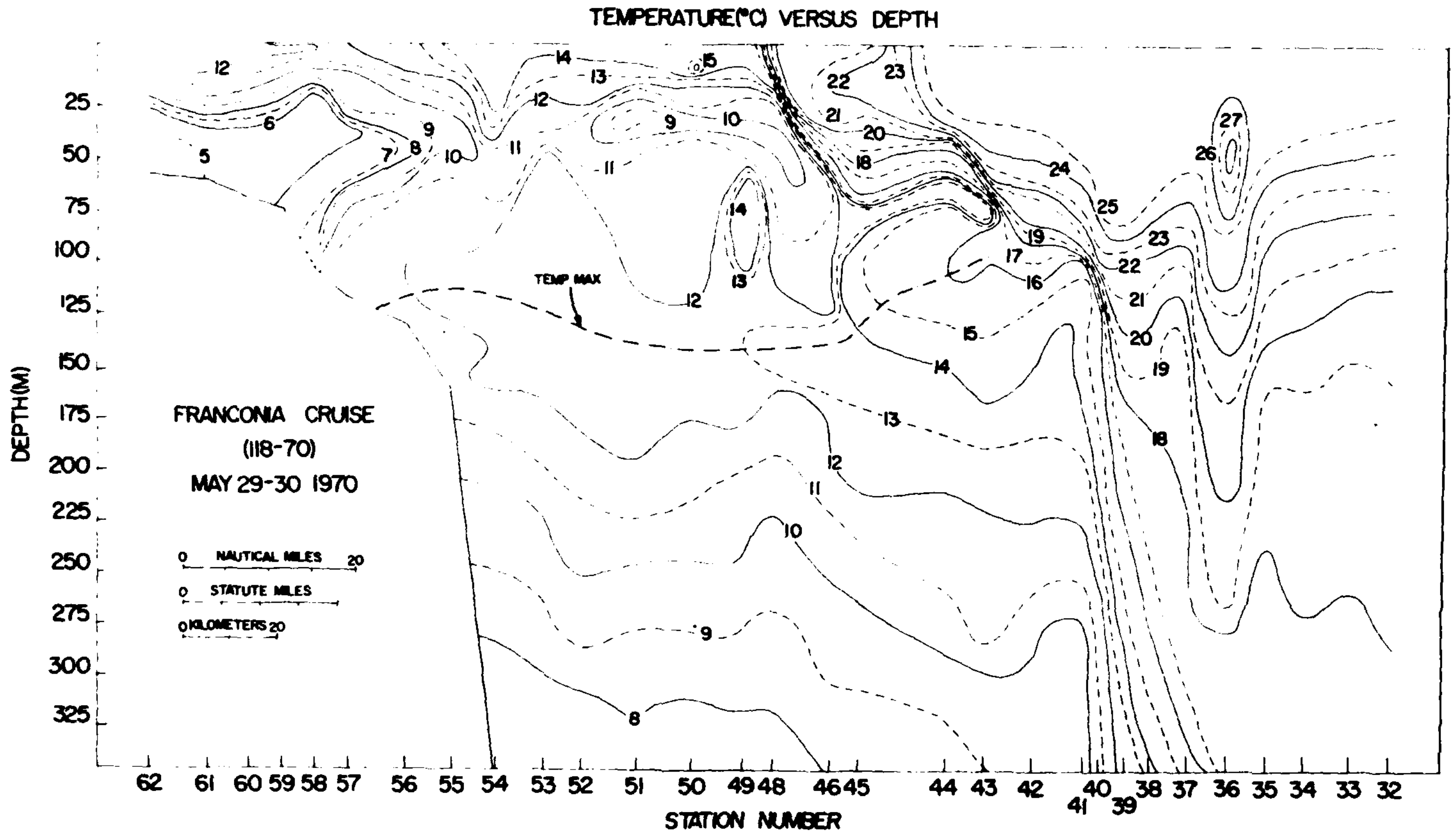

Figure 4. Temperature Distribution in a Transect of the Slope Water Gyre, from 60 m isobath to Past the Gulf Stream Bowman and Weyl (1972).

considerations is the concentration of coliform bacteria per unit-mass of seawater (or river- or lake-water) near a sewage outfall. Although these bacteria themselves are harmless, their presence is considered to be an indicator of infection danger from other bacteria or viruses of human origin.

It is far from clear that the same approach or some simple adaptation of it will be adequate in assessing the effects of long-lived toxic metals or organic compounds in the sea. One difficulty is that concentration per unit-mass of seawater of a given substance at a given location is a random variable. Relatively close to a pollutant source the concentration is high when the current flows from source to receptor (fumigation), low otherwise. A conservative approach is to focus on periods of fumigation only, and judge the effects of the pollutant on that basis. This is the traditional "worst case" strategy of engineering design. The practical consequences of such an approach may be unnecessarily costly (e.g., it may lead to the choice of a very long sewage outfall pipe) where the probability of the worst case scenario is low.

A more subtle and far more difficult complication is connected with a fact discussed at some length earlier: most heavy metals and difficult organic substances reside preferentially in the particulate substratum of the ocean, rather than in the water column. Living organisms of the sea, in effect, exist on this substratum. Many such organisms are small particles; they eat small particles and excrete small particles. Larger organisms eat the smaller ones and tend to concentrate certain toxic substances within their own body tissues. Thus, any damage done by pollutants to some marine species is effected through the particulate substratum, and the concentration of the pollutant in unit-mass of the substratum is what counts, not the concentration per unit-mass of seawater. Owing to the many chemical and biological interactions between particles and the water column, other particles, or the sediment, the relationship of the two concentrations (per unit-mass of seawater or of the particulate substratum) is certainly not straightforward. Nor is the problem a simple source-dispersion-sink proposition; subsidiary sources appear in consequence of chemical or biological recycling.

As a practical measure, in monitoring pollution effects such as caused by mercury or a radioactive element, the concentration of the pollutant in the body tissues of a higher trophic-level species, such as an edible fish, is often taken to be the pollution index.[9] This focuses on the direct poisoning of human consumers, and may be somewhat insensitive as a general pollution index: highly undesirable ecological changes may occur without actually killing people. Examples are the extinction of bird species or the eutrophication of lakes. At the present time it is not clear what will turn out to be the most practical index of heavy metal or difficult organic substance pollution.

However, it is reasonable to suppose that a model yi... ng key statistical properties of pollutant concentration per unit-mass of the particulate substratum (such as the probability of exceeding a given threshold concentration) will ultimately be needed.

All pollution models are effectively mass balances, a bookkeeping operation on sources and sinks and the pathways between them. Because the intensity of sinks goes up and down with the concentration, it is, in principle, possible to solve the mass balance and calculate concentration. Of course, one has to be able to estimate the coefficients in such a balance, i.e., to select parameters characterizing the various physical, chemical, and biological processes involved. The simplest variant of this approach is a box model in which only bulk fluxes in and out of an oceanic region (plus in-situ decay) are considered. The most sophisticated approach is to use an advection-diffusion equation and to allow the flow field to vary in a random manner. Scientists uncomfortable with complex mathematical expressions speak of the mass balance approach (meaning some sort of box model) as if it were an alternative to the diffusion equation. That equation is, of course, simply a mass balance for each infinitesimal element of the space considered, and is only more accurate than a box model if the sources, sinks, and transfer processes are well enough known for quantitative parameters to be chosen realistically in such a detailed approach.

Oceanic pollution models accessible to the professional engineer today, described in the available literature, generally address only coastal pollution problems and are inadequate to cope with heavy metal or difficult organic substance effects. The predicted variable is concentration per unit-mass of seawater or some statistical measure of it. Secondary sources are not considered, and decay is represented by a term linear in concentration. While in their present state these models are not very much help, they point the way to further necessary idealizations and the more sophisticated representation of processes in the particulate substratum. A brief survey of these conventional models follows, based on one of many recent publications.[10]

The box model is illustrated in Figure 5. Predicted variable is concentration in the box. Control is mostly by the flushing velocity U, parallel to the coast, and the mass-transfer velocity v_e, perpendicular to the coast.

The plume model. See Figure 6. A large initial cloud is diluted in a steady current. With continuous release, a "plume" is formed. The concentration at the center of the plume decreases slowly as ambient fluid is mixed in from the sides.

Tidal source extension model. Figure 7 illustrates the trajectories of particles released from a continuous source at different phases of a tidal cycle, if only tidal motions are present.

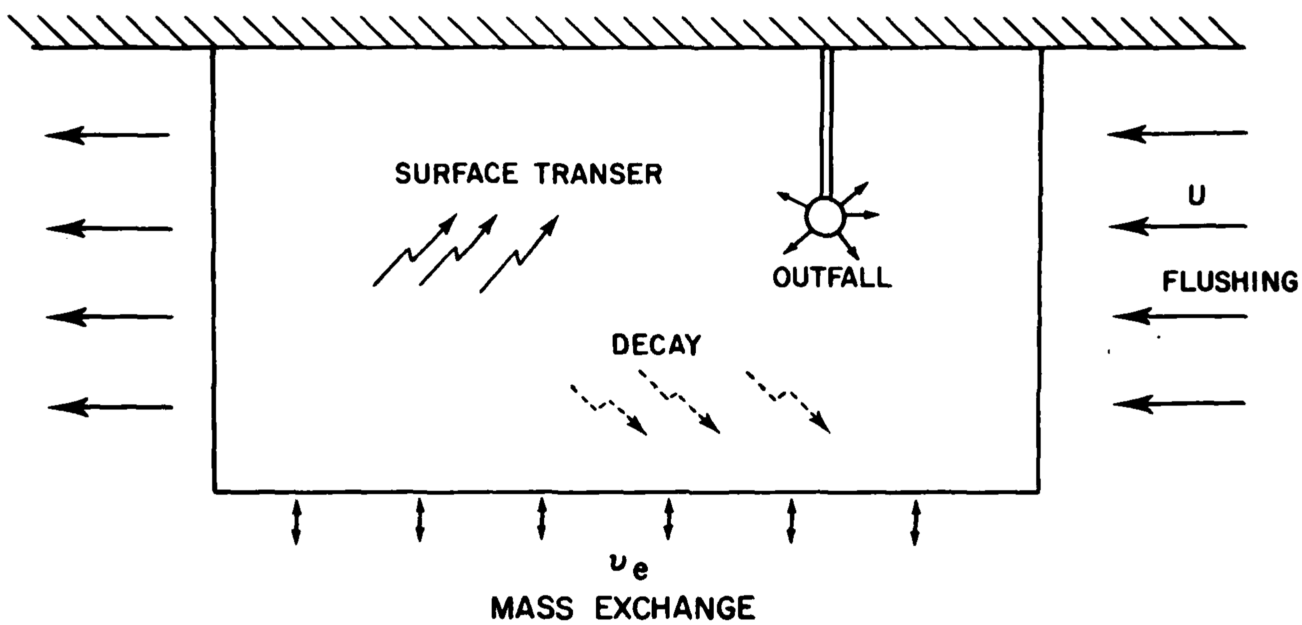

Figure 5. Box Model

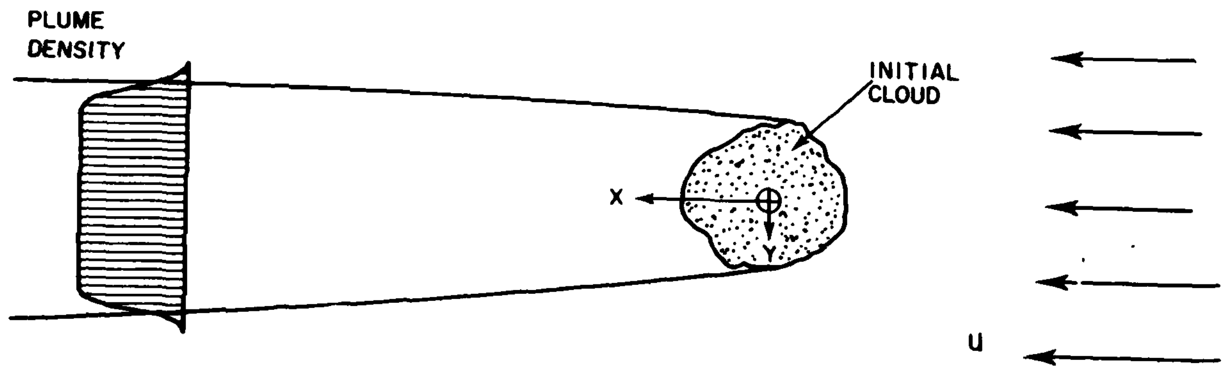

Figure 6. Plume Model

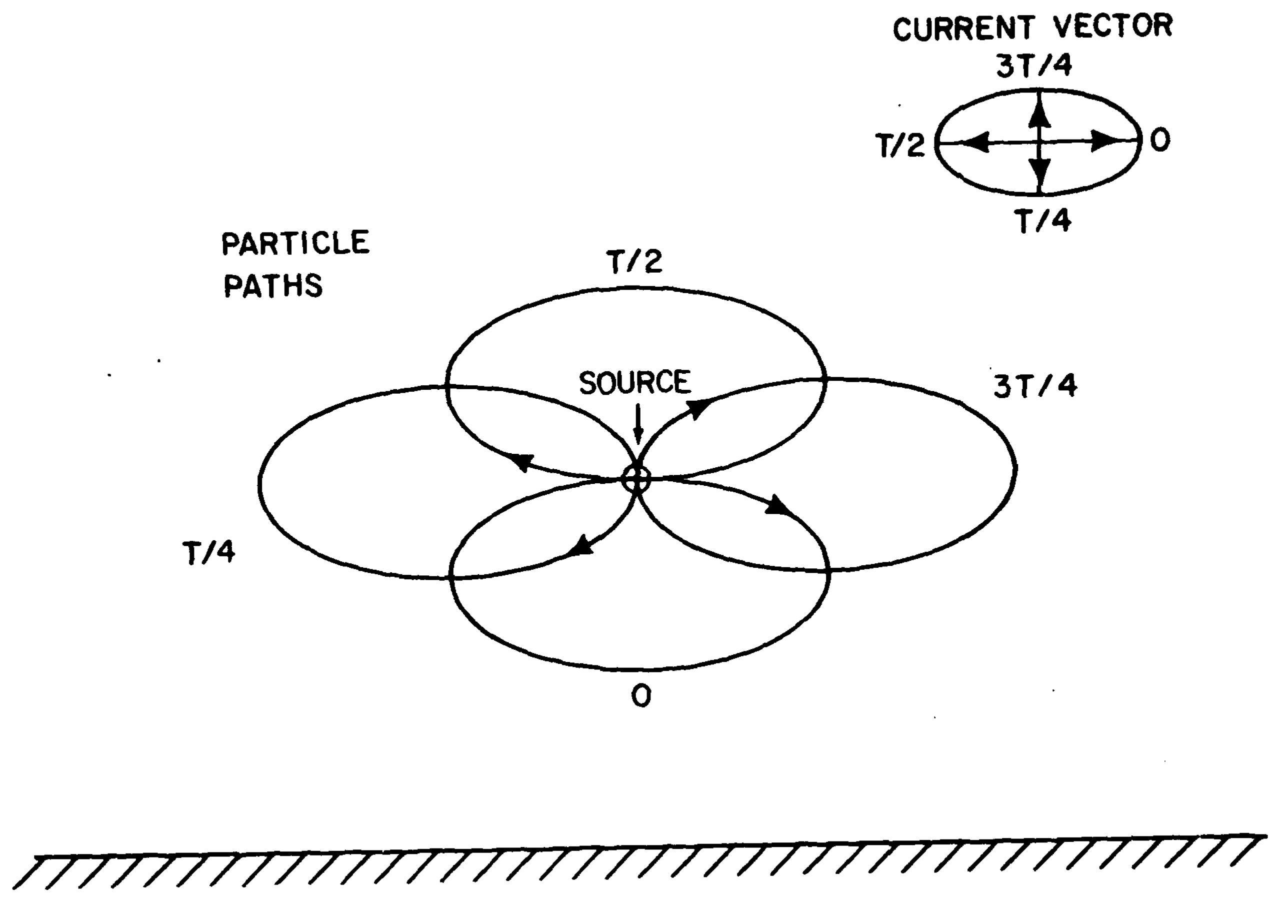

Figure 7. Tidal Source Extension Model

The effect is much as if the source moved (in the opposite direction to the tidal motion) over an equivalent area, and distributed the pollutant over it.

Fumigation model. In addition to what is happening within a plume, it is also important to determine how frequently a plume hits a given target point. Figure 8 shows a calculated distribution of fumigation probability (frequency of time for which plume is near enough to cause significant concentrations at receptor point).

Escape probability model. Another version of the fumigation model, useful especially at short distances from a source, is to focus on the probability of plume presence per unit-area of a boundary surface, approximating it by the probability of escape, which can be calculated under certain assumptions. Figure 9 shows a calculated distribution of this kind.

Dilution probability model. Combining fumigation frequency and frequency of achieving (at least) a given dilution in a plume, one arrives at contours of constant probability of a given dilution.

Models such as these either suppose a conservative substance, or one with a given decay rate (proportional to concentration), and no interaction with the sediments. The inadequacy of this approach for pollutants residing in the particulate substratum should be abundantly clear form remarks made earlier. A great deal of work clearly needs to be done on the further development of engineering pollution-prediction models.

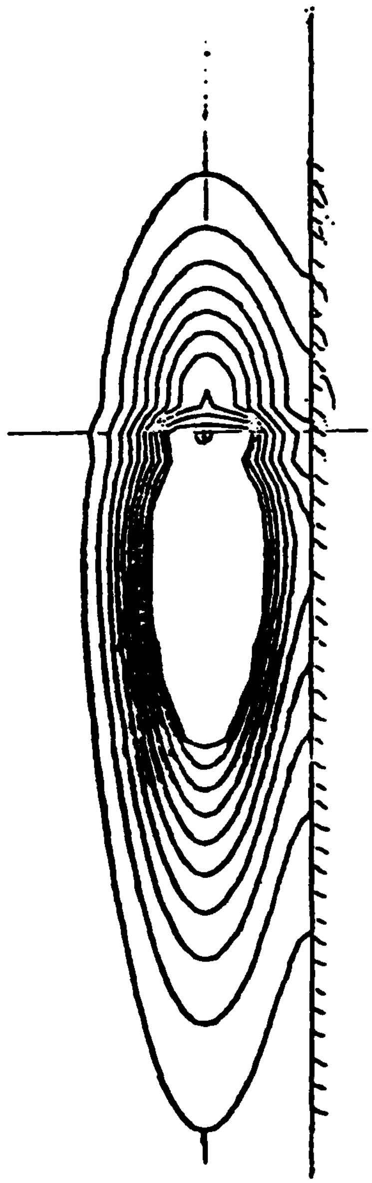

Figure 8. Fumigation Model

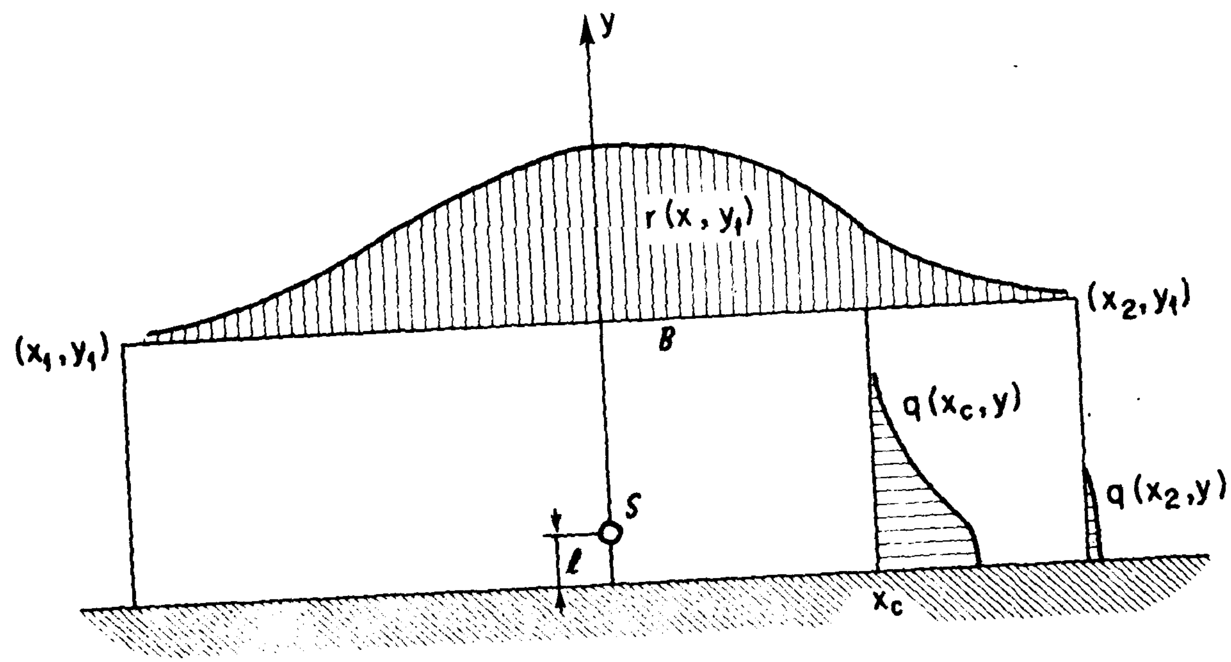

Figure 9. Escape Probability Model

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DISCUSSION

MEEKER: Dr. Goldberg spoke of the process of eutrophication as presenting problems in a number of bodies of water around the world. I am wondering what part of eutrophication you would think is proper to attribute to disposable sewage as opposed to industrial and chemical wastes?

CSANADY: Certainly eutrophication is not related to industrial waste. It is related to fertilizer input in one way or another. It is simply overfertilization, and to the extent that my limited knowledge of this problem goes, I would say you can try to control the sources or you can make sure that you utilize the fertilized waters in some realistic way, such as aquaculture.

COLWELL: Eutrophication can occur in deep ocean waters. We have been studying the Puerto Rico Trench area for the last 10 years and, specifically, the last three years we have done studies at the pharmaceutical waste dump site. We have been able to detect microbiological changes in the surface waters of the Puerto Rico trench dump site where "eutrophication" occurs when the pharmaceutical waste is dumped. Eight cruises have been accomplished, the most recent cruise taking place within the last two days. Very clearly, a change in the microbiological population occurs which is persistent. Microorganisms usually associated with hospital environments, including Staphylococcus aureus, a species which is coagulase positive and pathogenic can be detected at concentrations of 10^5 cells per millimeter in the Puerto Rico Trench surface waters.

There are two points to be made. One is that physical oceanography data that was available indicated that the currents would sweep the surface waters from east to west. We found that, in fact, there is, as described; this kind of a circular motion of the surface waters, with a concentration of dump-related bacteria in the northeast corner of the dump site area. We are able to detect these bacteria after the dumps occur, and so this is evidence for biological change which may be very important.

Another discovery we have recently made is that, by applying the technique of epifluorescence microscopy, what one terms "die-off" really does not always happen. What occurs is that bacteria, such as E. coli, Staphylococcus, etc., do not grow on the usual media employed for recovery of these species, after "stress," such as exposure and or adaptation the seawater. Examination of samples by direct microscopy for viable cells, shows that they increase, even though they are not recoverable. So, the so-called "die-off phenomenon" may be quite misleading. We may have persistence of these bacteria, the potential pathogens, in seawater, and there may be "bacterial eutrophication"

not recognized in the past. This emphasizes, I think, the point that Dr. Goldberg was making, that eutrophication effects can occur in the surface waters of a deep trench region.

WIEGEL: Would you please define persistence? And then you said something about 10^5 per million. I do not know what you mean.

COLWELL: I am sorry. As a bacteriologist, I have to remember that I am speaking to a totally different audience than that to which I am accustomed.

Transects through the Puerto Rico Trench dump site east-west, as well as north-south, have been made over the past several years. We just completed sampling at stations in the trench that were in a trackline from Barbados to Bermuda, through the Puerto Rico Trench dump site.

We observed the presence of pathogens in the surface waters of the dumpsite, i.e., the kinds of "freshwater" type of bacteria normally associated with human disease increases markedly within the trench. And as you pass through the dumpsite these decrease. Some of these bacteria are the same kind one would pick up in a hospital: Staphylococcus aureaus--possibly, we are not certain, but possibly--a test strain for determining the potency of antibiotics produced in Puerto Rico, the wastes of which are dumped in the trench.

We have also picked up other, gram positive bacteria, freshwater bacteria one normally does not find in the deep ocean. And we have found that the kinds of bacteria that comprise the natural marine bacterial populations decrease. In fact, right after a dump we have monitored bacteria in the waters of the plume, and recorded a decrease in marine bacteria and an increase in freshwater bacteria from the wastes.

WIEGEL: In regard to persistence, do you mean there is no die-off whatsoever?

COLWELL: Apparently, not in the case of Staphylococcus. We have isolated these bacteria from the trench surface waters in the laboratory put them back in seawater with the waste, and they do very well. We think they utilize whatever it is that is in the waste. They persist in the waters and remain viable. I think where I confused you was that in the case of some of the indicator bacteria like the coliforms, E. coli, we have found that in seawater, as you increase the salinity of the suspending liquid to the full strength of seawater, they do undergo a phenomenon whereby they are not recoverable on routine media. It appears that they die off, but when you examine the culture under the microscope directly, they in fact, do remain viable even though not recoverable on media.

DITMARS: You point out rather clearly the difference in time and space scales of motion as you go further offshore and the concern with the type of waste and difficulty of looking at longer-lived wastes at some of these time scales. In fact, from the physical oceanographic point of view, things start to get rather complex when you get off on the slope and so on. My question is related to this business of prediction and to make slightly more distinct a definition of prediction between prognostic and what I would call diagnostic type prediction. That is, if one hoped to predict these kinds of motions in a really prognostic way, things look rather dim, it seems to me, except for maybe on the shelf. But you made the link rather clear, it seemed to me, between trying to make predictions in the engineering and science mode. There may be partially a way out of the problem by dealing in a more prognostic sense, that is, using measurements with what physics we understand about what happens with the slope waters to make predictions of the sort that you showed, of the probability of plume existence at a point or a concentration.

I wonder if you could comment on what you see as the hope for making longer term predictions than one or two days, but, say, shorter term than 30 years--a big gap there-by means of prognostic prediction?

CSANADY: Certainly that is the only reasonable way to do it today, take a current meter and then try to come up with some kind of statistics of displacement that you can somehow generate from that. It is not an accurate prediction, but at least it gives you some kind of an idea of where particles might go.

This is about the only way people have been able to deal with this so far. Perhaps we can improve on that a little more in the future as we understand more about the habits of the ocean in certain areas.

GERWICK: Dr. Csanady, you discussed primarily the role of the currents and the concentration of these waste products, but to what extent do yo think the short-term extreme events, such as storms and shedding by the major currents and so forth, act to disperse these concentrations, and what effect do they have on the long-term effects of waste disposal?

CSANADY: All those motions are parts of the spectrum of oceanic water movements, and they certainly help dispersion because on one occasion an eddy moves a particle from a given area in one direction, on another occasion somewhere completely different. This is, also, true of storms. That is, only in the overall sense can we talk about the general drift going in a given direction along the coast. On any mean motion there are always superimposed, like on that spaghetti diagram that I showed you, many complex transient motions. And while deterministically you could not say where any particle will go on any

given day, you can--I am quite sure that it is possible even today--come up with probabilistic forecasts for certain pollution events. The Bureau of Land Management has such things for oil spill forecasting and the licensing of drilling operations. I understand that they have a probabilistic forecast of what might happen in 20 years--what is the probability of anything going from A to B and C and with contours of how probably a specific area would be hit. This is the kind of model that really we have to use for other things.

GERWICK: I think it is very important to take into consideration such phenomena as a 100-year storm or things which may occur once every 20 years, but it may have a tremendous dispersal effect and more or less clean house.

CSANADY: Once in 20 years, that is certainly true, if we can somehow quantify those things. The tail end of a probability distribution is always the problem.

HIRSCH: You did not mention atmospheric transport as a factor.

CSANADY: No, I have not. There is some exchange, and there are certain materials that are subject seriously to exchange across the air-sea interface. Such dispersed problems are more complicated, involving transfer from one fluid to another fluid.

HIRSCH: I wonder if you have any views as to how significant that might be in terms of ocean pollution?

CSANADY: I know that there are people who investigate, for instance, the fate of lead in the ocean, most of which comes from the atmosphere and deposits at the surface and then eventually reaches the sediment. But clearly that is just a different source function. The sinks are still the big problem. This kind of thing is right now the subject of vigorous research. I have seen recently very good papers that tell us a great deal about the ocean once they sort out where the actual absorption or the final removal of these lead particles takes place.

STEVENS: You mentioned that the particulate matter, the sediments of the ocean bottom, may be reintroduced into the water column by resuspension by the boundary layer flow. What is the role of the bioturbation in removing contaminants from an area?

CSANADY: It is a very important role in at least two ways. If you take just the simple movements of organisms in the water column that means that particles are taken to a different level. At one level they move with the flow along one isopycnal surface in some specific direction. Taking them up somewhere else in the water column gets them into another flow regime. Shear within the water column is a very

important factor. I know from similar atmospheric dispersion problems that the same effect is important in, say, the dispersion of dust particles in the atmosphere. Similarly in the ocean where we do not just have settling particles, but we also can have upward movement within the water colums, this is going to be that much more important. And then of course within the sediment, the bioturbation--the term that is normally used to describe transfer within the sediment--that, of course, is part of the sink-source mechanism at the seafloor. And whether it is a sink or a source very often depends on just what the precise chemical transfer mechanisms are. Those mechanisms can interfere with the sediment after it has somehow got there by a physical process, a biological process, or a chemical process combined with some biological activity, and release the same material again. So, this is what complicates the matter so much--because of this difficult complex of interactions taking place not only in the water column but also in the sediment.

STEVENS: So, therefore, if the marine organism takes the particulate matter, let us say 11 inches below the sea surface or the ocean bottom surface, is that lost forever or is it introduced, reintroduced into the water?

CSANADY: In many places it is reintroduced. Many factors come into that, of course. Here I am really venturing far out on a limb myself. I don't know very much about the chemistry and biology of sediments, but from a physical point of view, I understand that it depends on the chemical reactions within the sediment: what the chemical environment is, for instance, and whether there is oxygen and, also, on the physical effects there, is there much turbulence above the bottom or not. The combination of these effects is fairly complex but from my point of view it determines whether that particular area of the seafloor is a sink or a source.

GAITHER: What do you regard as the most important research problems to be attacked now to help with this question of assessing the assimilative capacity of the ocean? What part would you give your greatest attention to?

CSANADY: I think it is the sinks. When the environmental impact statement was prepared for the New York Bight in connection with possible shifting of the dump site for New York City sewage, there was a long description of various factors involved there. But one thing that stuck out was that although they were dumping sludge there at one site for many years, nothing really terrible occurred. An anoxia event was later shown not to be directly related to this long-term sewage dumping. But what was particularly unclear was what happened to that sewage sludge. Just where were the sinks? What happened in the 35 or so years of dumping there? This problem with the sinks in the ocean, I think, is a general problem. We are talking about particulate

export from the shelf onto the upper slope, and there is a major hypothesis that the upper slope is a really important sink region. It is not known whether this is so but if we knew that, if we knew the distribution and strengths of the sources, we would be in much better shape to make "back of the envelope" calculations on what happens to pollutants in a given area. For the Puerto Rico example that was brought up, we do not know why pollutants linger alone or there. At the deep-water dump site you cannot find anything that you release, so the intensity of the sinks must be well. The lifetime of pollutants in the ocean is very much a function of the intensity of sinks. I think that is the key problem really, when we come to face the longer-lived pollutants.

GAITHER: It seems like there are two different ways to look at this. One is the New York situation where there apparently was little attention given to the sinks and their strengths; rather wastes were put there because it was convenient to put wastes there. You are really saying, if I hear correctly, that we should first identify where the natural sinks are and determine their strengths and then relate dumping areas to those natural sinks. Is that correct?

CSANADY: That would be much a more rational procedure, of course, if we could do that. In New York City's case people assumed that there would be no ill effects, and they were right, but whether that would hold in another situation is certainly questionable. So, if we knew something more about--a lot more about--the sinks, we would be in a much better position to make a judgment.

BROOKS: If the sinks are so hard to find they must be rather weak and widely distributed. Is that right?

CSANADY: Not only that, but really the ocean is very large. The ocean is typically 5 kilometers deep, and it occupies much more of the earth's surface than the continents. So, where are the sinks? We do not know. We do not really know very much about the ocean.

WIEGEL: This has been mostly on the East Coast, on the continental shelf. On the Pacific Coast--at least, California, Oregon, and Washington and so forth with the extremely narrow shelf--the process is an upwelling. So, I guess we have to very carefully look at the particular areas for waste disposal because they are, again, quite different.

CSANADY: Absolutely. There is a big difference between the two coasts. The Pacific Coast, with the much steeper slope, is a much more suitable location generally than an Atlantic type coastline, such as the Gulf of Mexico. We are lucky on the East Coast because we have a fairly active ocean just beyond the continental shelf, but there are other areas, such as perhaps Puerto Rico, where this is absolutely not the case which means, of course, one has to be extra careful.

ASSIMILATIVE CAPACITY OF U.S. COASTAL
WATERS FOR POLLUTANTS

by

Donald Phelps*

Abstract

The following points are discussed:

1. Is there an available biological effects data base currently suitable for practical application for assessing the state of environmental health of the nation's coastal water and their assimilative capacities? No: Emphasis historically has been placed on the development of biological effects data in support of Water Quality Criteria. First priority has been given to controlling toxicants before they are permitted in the environment. As a result, the bulk of biological effects data for marine biota now available has been generated in laboratory bioassay systems. Recently, the need for verifying that data under field conditions has received increased attention.

2. Is there empirical evidence to suggest that the assimilative capacity of the ocean may have been exceeded to date by man's activities within the coastal regions of the United States? Yes: There is limited data to support the fact that for some species, the assimilative capacity of the ocean may have been exceeded. In other cases, the ocean's assimilative capacity may have been exceeded in some geographical areas, such as the Baltic Sea.

3. Are there techniques currently available to measure biological effects in the open environment that may be applied to answer questions of the relative health and/or assimilative capacity of coastal environments? Yes: There is now a limited but growing data base that may be rapidly enlarged through application of some new biological effects monitoring techniques.

4. The U.S. Mussel Watch Program has identified "Hot Spots" where the assimilative capacity of the oceans may be jeopardized or challenged. Techniques for determining <u>in situ</u> biological effects have been demonstrated. This approach relies heavily

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on the use of a biological sentinel as a surrogate for other biological systems and more complex organizational levels. Research activity to investigate the conservative limits of the use of such a surrogate biological system is strongly advocated.

"Research to date has shown minimal long-term detrimental effects from ocean waste disposal. This suggests that either the ocean is the best medium for the disposal of certain wastes, or that the effects of ocean wastes on human health and the environment are more subtle than supposed. A third possibility is that past research on the effects of ocean-waste has been inadequate or misdirected." This is one of the closing paragraphs of the final chapter of a 1981 report of the National Advisory Committee on Oceans and Atmosphere.[1]

There is little doubt that historically, studies on biological effects have failed to show convincing cause and effect relationships between the presence of pollutants and deleterious effects on marine biota at the individual, population, or community level. Population or baseline studies, perhaps the most visibly applied attempt at field demonstration of impact due to man's activities, show reduced species diversity and increased biomass of the remaining species in areas of ocean outfalls and dumping sites. So what?

Fin fish with fin rot and tumors have been associated with some outfalls and dumpsites, but not with all such sites. Levels of incidence change from year to year, and symptoms have been observed to occur in control sites, as well as in areas known to be impacted directly by the input of anthropogenic wastes. Of course, fish tend to migrate. Sometimes tumor formation does not show up until a considerable time lapse has occurred between time of exposure and the occurrence of the symptom. In the case of humans, that time period can be as long as twenty years between exposure to a carcinogen and the detection of cancer. By the time a resulting symptom appears the causative agent may well be long gone, especially in the marine environment where the fish may be far removed from the exposure site.

There is a plethora of excellent data on biological effects that has been generated in laboratory bioassay systems. Specific cause and effect between toxicant and biological deterioration have been well demonstrated. However, to date there has been no concerted effort to field validate those results. The data have not yet been challenged with extrapolation to the complexities of the field where there are interactions between other biota, a highly variable physical and chemical natural environment, and the presence of diverse kinds and combinations of toxicants.

Marine environmental biology is not yet a predictive science especially when it comes to understanding the long-term implications that may be attributed to a given amount of pollutant which may be allowed to be introduced into marine systems. It does not, as a discipline, interface well with the engineering challenge that says, "tell us what the safe level is and we can design a treatment and disposal system that will meet that level."

At the height of the Roman Empire, the historical precursor to the engineer had designed aqueducts and sewerage systems that still show sound engineering principles. At the same time, and in that same place, the historical precursor to the biologist was most probably the local high priest who practiced the biological/mystical art of heruspex. Heruspex, as you must recall, is the biological examination of sacrificial animal entrails as a way of assessing the present and future level of a kind of environmental quality. If the liver, etc. looked good, one received the blessing for whatever activity was under consideration. If it did not look right to the high priest/biologist, one did not get the blessing.

Things really have not changed that much since those early roots of our respective professions were beginning to take hold. The biologist is still a sort of scientist/mystic in that he is still concerned with and more or less accepts the responsibility for understanding and protecting what in many cases still remain to be those "mysterious life processes" and interrelationships that inexorably link man, physically, to the simplest life form as well as his physical and chemical environment. The engineer with his technological dexterities has now landed us on the moon and extended our eyes and ears electronically out into the farthest reaches of our solar system. This is remarkable progress from the days of the Roman Empire. Meanwhile, in a very real sense, the biologist still practices heruspex when it comes to auguring the present and future state of marine environmental quality. Among some other measures, we still examine the liver of the fish for toxic concentrations of pollutants and presence of pathologies. We still examine the entrails of mussels for tissue residues of pollutants.

These statements are not meant to be in the form of an apology for biological science. They are meant to focus on a problem that seems to have escaped consideration as one of the alternatives outlined in the quoted paragraph at the beginning of this paper. This problem is the ability of the biologist to develop adequate tools for demonstrating biological effects due to man-made stress, under field conditions typical of the marine environment. The first alternative offered, "that the ocean is the best medium for the disposal of certain wastes," is certainly still a question to be answered through a variety of avenues, one of which remains marine environmental research. The second, which offers that "effects of ocean wastes on human health and the environment are more subtle than once supposed," lacks meaning since the original supposition referred to is not defined. Perhaps

the recasting of this statement to "...more subtle than our abilities to measure them," may take us closer to the heart of that problem. The final possibility raised is that of "inadequacy of past research," which may well have been the case providing our limited abilities to measure effects on a level appropriate to the question asked is included. The question of misdirected research is of course a value judgment.

In a very real sense, research attempts to relate biological effects to toxicant levels of pollutants in the marine environment have been caught on the horns of a dilemma: on the one hand, if the biological system is dissected down to the level necessary in order to relate a specific biological impairment to a clearly identified toxicant level, the information is so specific that it is no longer meaningfully applied to the complexities of life in a stressed ocean system. Biologists can demonstrate impact, in laboratory systems, in diverse biological mechanisms which range from the organism molecular level to schooling fish behavior with equally great skills. Demonstrated impacts range from death within a 96-hour period, to mutagenesis, which may result in neoplasm formation developed after a considerable period of time has elapsed or which may impair a population's genetic integrity. Such genetic shifts within a population, resulting from some "mindless" dumping activity of man, may lead to an unknown evolutionary blind alley for some biotic entity.

On the other hand, we have developed field tools which in summation all too often seem to be out of synchrony with the observed effects on field populations, such as disease, reduction in reproductive capability, etc., and the presence or exposure to pollutants.

Until recently, we have been frustrated with the ample evidence developed in laboratory systems that many pollutants known to be present in the environment cause serious problems to marine life as well as to man, but we have lacked the ability to demonstrate such effects under field conditions. Yet we are plagued with the awareness that there continues to be evidence, albeit piecemeal when considered in the light of vast oceanic systems, that we have pushed some parts of that system dangerously close to a point where assimilative capacity has been exceeded. Case histories based on some localities and species remind us of this fact.

The brown pelican, which was pushed to a point where successful renewal of its population had clearly placed the species at the brink of extinction due to the presence of DDT in its food chain, is one such example cited in the NACOA report. Regulation of DDT brought the species back from that brink. Currently, Risebrough reports widespread problems in the reproduction of sea lions and seals.[2] On

the Farrallon Islands off the California coast as well as within San Francisco Bay, there is a high rate of premature birth of the pups of those marine mammals. In Puget Sound, a high incidence of birth abnormalities and deformities are noted in pups. In the Baltic Sea, harbor seal populations are being seriously reduced as a result of a uterine disease that causes natural abortion since embryos cannot implant properly within the uterus. All of these incidences, wide-ranging geographically, are related to pollutants in the environment and to levels of pollutants within the mammals as well. We clearly see the evidence and continue to be frustrated with the lack of those tools which may show specific cause and effect on such a broad scale.

Within the NACOA report, reference is made to levels of PCB's in marine biota. The report notes PCB's and lead are being put into the New York Bight as well as into the Southern California Bight at relatively high levels through sludge and effluent dumping. Levels are then contrasted between the two sites. The conclusion is drawn that since levels of PCB's in the New York Bight are still below some levels observed in the Southern California Bight and elsewhere in the world, and since no broad scale effects have been attributed to PCB's, it would be reasonably safe to increase PCB's in the New York Bight to some higher level.

The U. S. Mussel Watch Program has produced a data set which not only puts the PCB and lead levels in the New York Bight in perspective with those found along the Southern California coast but allows comparison with levels found along the remainder of the United States' coastline. Seen in that light, PCB levels in both the aforementioned areas stand out in very high profile against the rest of the country's coastline (Figure 1). We find, in general terms, an order of magnitude difference between the level of PCB's in mussel tissue between both of these areas and the rest of the stations measured. Similar order of magnitude differences are reported for a variety of hydrocarbon compounds between these areas and the rest of the country's coastline. We find, in general terms, an order of magnitude difference between the levels of PCB's in mussel tissue between both of these areas and the rest of the stations measured. Similar order of magnitude differences are reported for a variety of hydrocarbon compounds between these areas and the rest of the country. Several fold increases of lead are similarly observed.

Viewed from this national perspective, one notes that a widespread area of elevated levels of these materials, some of which harbor known carcinogens, exists along the northeast coast and radiates out from the New York Bight area in relatively great coastal extensions in both directions. Bioconcentration certainly is one of the recognized effects of ocean dumping. The Mussel Watch data set suggests that in those terms, biological effects due to man's activities are clearly visible whether it ' from deliberate ocean dumping activity, which

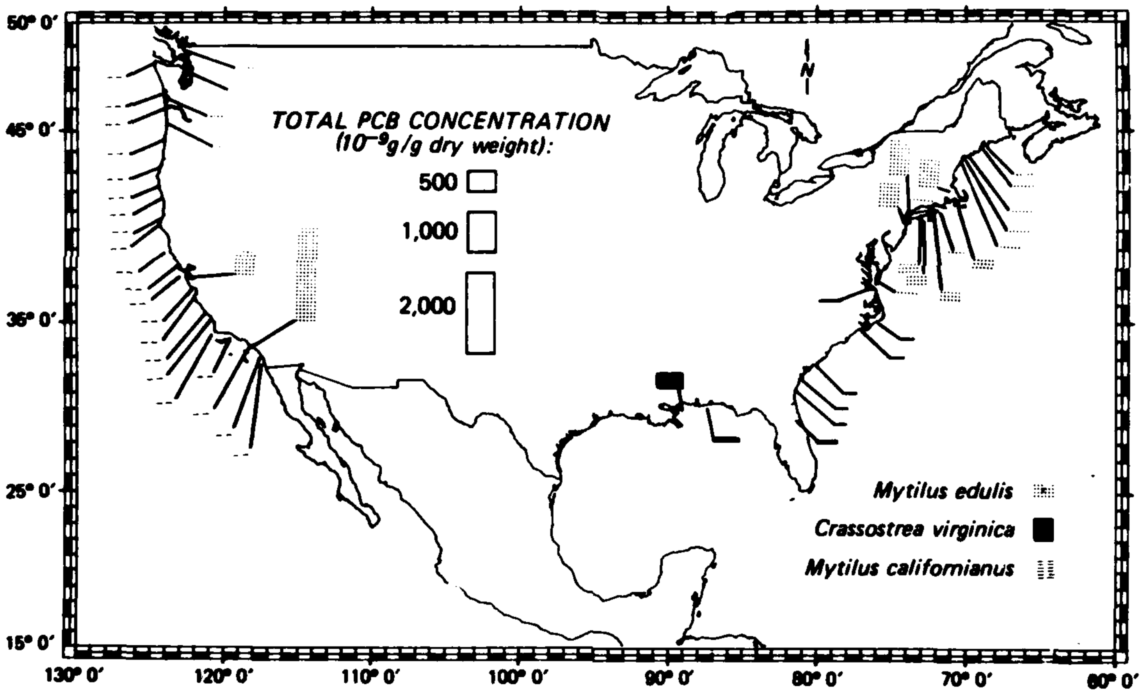

Figure 1. PCB Levels Analyzed in Bivalve Tissues as Reported from the U.S. Mussel Watch Program, 1978.

favors dispersion of materials, or from that activity in conjuction with the less intentional forms of ocean dumping that occur from nonpoint sources including atmospheric as well as riverine input from land runoff.

The U.S. Mussel Watch data for PCB's raised an alert to potential problems in the Acushnet River and New Bedford Harbor, Massachusetts. Subsequent investigations have shown this area to be a concrete example where assimilative capacity has indeed been exceeded.

Concentrations of PCB's found in tissues of lobsters and commercially important fin fish species from the area exceed U.S. Food and Drug Administration (FDA) limits for human consumption. The area has been closed to fishing activities by the State of Massachusetts. The resulting loss to commercial interest of that "renewable resource" exceeds several million dollars annually. Tagging studies demonstrate that the black back flounder as well as lobsters from this area migrate offshore annually where they may be caught and sold commercially in spite of the local prohibition limited to Massachusetts waters. While the potential hazard regarding human health has yet to be assessed fully, the fact that some seafood which exceeds FDA limits for human consumption because of PCB's may be reaching the market place is a sobering reminder that in fact we can exceed the assimilative capacity of marine systems as a direct result of the disposing of industrial wastes.[3] The problem may appear to be a very localized one, however, the implications on the broader scale are neither yet fully appreciated nor understood.

As biologists, we are concerned with the presence of toxicants in biological systems, but are still frustrated at not being successful in assessing effects on that scale of "total assimilative capacities of the ocean" to the level that suits our collective consciences. Recently, it has been shown that extract from mussel tissue having levels of PCB's and petroleum hydrocarbon not dissimilar from those levels common to both the New York and Southern California Bight areas have produced positive reactions in an enzyme induction test for potential mutagens.[4] This result is preliminary but important from two points of view. First, it suggests that tissue levels of the toxicants common to some of our coastal areas are related to genetic damage in some marine populations. Second, it demonstrates a new kind of methodology that holds promise in assessing biological effects due to ocean dumping that may eventually give greater insight into such questions as the "assimilative capacity of the ocean."

Two workshops were held in 1979 that had significant input into the NACOA report: the Crystal Mountain Workshop[5] and the Estes Park Workshop.[6] Since those meetings, there have been two additional meetings devoted exclusively to biological aspects of marine pollution, including problems of monitoring: ICES Workshop, Beaufort, North

Carolina,[7] and Biological Monitoring of Marine Pollutants.[8] The proceedings of these workshops instill a real sense of hope for the future of monitoring biological effects in the marine environment. While some of the techniques discussed have not yet been field tested, others have proven to be very effective in demonstrating biological effects due to pollution, under field conditions.

It is logical and consistent that if there are only three basic media through which man can dispose of his wastes, all three must be considered and carefully evaluated as alternatives: the air, land, and the oceans. However, for a variety of reasons, demonstration of biological effects due to anthropogenic inputs into marine systems has proven unsatisfactory on the whole for the concerned biologists as well as the engineer and the decision makers. A lack of evidence, based on the state-of-the-art of biological methodology, should not be used as a carte blanche for selecting the oceans as the alternative of choice.

Methods have recently been developed that may be employed in meaningful monitoring strategies. The U.S. Mussel Watch Program has demonstrated that national monitoring for pollutants using biological sentinels is feasible and useful especially in providing a perspective on the relative degree of problems that may be perceived. Monitoring biological effects has achieved a level where it is now possible to link such activity with monitoring of chemical residue in the Mussel Watch approach in a productive and synchronous manner. It is strongly urged that such a long-term, broadscoped effort, that includes monitoring chemical residue as well as biological effects, be instituted as a background against which similar monitoring efforts around the areas of ocean disposal activity may be meaningfully assessed.

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DISCUSSION

PALMER: I have a couple of questions about PCB. First of all, how was the FDA standard set, and second, in the case of sewage sludge, is PCB concentrated enough to consider removing it from sludge or is it too diluted to even consider that. I know, for instance, Sun Ohio has a process for removing oil. Is that feasible?

PHELPS: Larry Swanson might be able to answer that question.

SWANSON: We went through the calculations several weeks ago using a process recommended by several different authorities on PCB. To apply it to a large city you are talking about a several billion dollar a year operation to remove PCB from the sludge because it is not concentrated.

PALMER: How about the FDA standard?

PHELPS: There are two standards, one for shellfish and one for fin fish. I do not know the process used in setting those standards.

SEGAR: I have a couple of questions about the PCB slide you showed. You showed essentially what I believe are two or three samples of all sampling locations and mixtures of those which were very high and made some generalizations about the Southern California coastline. Where were those samples taken; how many were there; and at what different sites were samples taken?

PHELPS: There were a total of 106 stations around the nation, and the relative levels for each station were indicated on the slide.

SEGAR: That is correct, but as I remember it, the samples were taken very close to the Hudson River.

PHELPS: The PCB levels are between three and six hundred parts per billion in that general area. The general area runs from Northern Massachusetts to Southern New Jersey and does not necessarily reflect a localized effect of the Hudson River.

GOLDBERG: They were repeated one after each other in 1976, 1977, and 1978.

PHELPS: These are samples taken directly along the coastline. It is important to point that out. The dumping activities in relation to the New York Bight take place a number of miles offshore. There are in all probability inshore sources of PCB, a few of which appear to be much larger than the others. So drawing a relationship I did between the two, mussel tissue levels and dumping activities, is somewhat hypothetical.

ENGLER: You have described a very bleak scenario for the waste manager. What does he do? Your agency develops the rules and regulations and the procedures, the protocols, the tests and so on for helping him out, but aside from assimilative capacity the waste manager has to make the decision beforehand. Where does it go; upland? in a stream? ocean? What general approaches do you see in the future? Right now we use bioassays. We use chemical tests. We cut livers to pieces. Where are we going in the next several years for an R&D standpoint?

PHELPS: I cannot speak for the agency. The point that I am trying to stress is that, for the first time, there are some effective biological monitoring techniques that are not predictive but rather provide direct demonstration of effects and could be used in field monitoring around dumping sites. Regarding the quandary that you raised, certainly I think the only answer to the question of where you put it has to get back to the statement that Ed Goldberg was emphasizing earlier. That is that given reasonable evidence of the impact within the three basic media (air, terrestrial or oceanic systems) that are available for disposal, someone has to sit down and make a meaningful decision based on economic and social as well as environmental terms. I am not certain that the state of development of methodologies to assess biological effects reflects a reasonable history in demonstrating effects in open marine systems.

GOLDBERG: You have got a very serious problem that really is not being addressed effectively by the R&D (Research and Development) community. I think Don Phelps's group is one of the few in the country that is attacking these terribly hard problems of biological effects, and the tragedy is so much money is being wasted on irrelevant research in marine pollution and biological effects.

COLWELL: May I continue discussion on that point, because I think Ed is correct. For example, the point I want to amplify upon is that we are not doing the right tests. We have looked at bacteria in areas where there is an abundance of heavy metals and other kinds of pollution. We find that there is a high frequency of occurrence of plasmids in the bacteria isolated from such sites, plasmids being transmissable, extra-chromosomal DNA (deoxyribonuclear acid). It is a bacterial response, so to speak, and the time frame for such a "response", may be a very good early warning system. It seems to me that such tests, combined with some molecular genetic studies is the path we should be taking, as opposed to the "entrails" approaches.

ENGLER: Another question, to Dr. Colwell, in relation to that. On the R&D level we can come up with various and sundry sublethal effects, chromosomal aberrations and so forth. How do you get company J to do this for waste management? The waste manager has 10,000 tons

of something he has to get rid of. How do we extrapolate the R&D to where he can go out and contract to some firms somewhere to tell him this material is acceptable or unacceptable for a waste medium?

COLWELL: There are three items to emphasize to answer your question. One is, as Ed pointed out, we have not been planning research dollars to get "cheap" tests. Nevertheless, the Ames assay is a lot cheaper than doing a biotoxicity or a bioaccumulation test, and it tells us a lot more.

Secondly, even if you turn your question around, we could engineer bacteria to remove PCB. Right now many studies are underway to develop "genetically engineered" bacteria to recover metals from wastes. If we put our attention to reversing this problem, i.e., developing strategies for recovery of materials from wastes, and actually put biology to work, we can get the kinds of answers that you need.

Thirdly, when the data are brought together from the kinds of quantification studies that have been done, we will see much better the patterns that may exist. Simply going out and making measurements, for which there are no correlations or correlatives sought, will not give us answers that are needed.

BROOKS: Ed Goldberg seemed to think that eutrophication was the major problem, but you implied by your talk that toxic substances were. What do you think about eutrophication?

PHELPS: I think there is good evidence that it deserves a high level of priority.

BROOKS: What may your concerns be?

PHELPS: Organic compounds, synthetic organic compounds. Also, I think we need a very carefully directed development of biological methodology. Such methods tend to be developed and dispersed like oil in the water. It is fairly easy to discredit data bases or try to institute other techniques or other approaches over some good existing data. There has to be some sensible agreement. I think more importantly, there has to be a long-term commitment of both time and money.

MATTSON: Are you suggesting that the biological effects research community associated with marine biology is the poor sister or weak sister of terrestrial and biological effects and human health effects associated with terrestrial and atmospheric disposal, or would you suggest that the weakness in being able to associate effects with waste disposal practices is something that exists across the board?

PHELPS: I think I would go back to statements made in the presentation. The ocean from a physical point of view is an extremely complex system to work with, or for consideration of the effects on and from the ocean due to loading the environment. It is so much more complicated. It is just more difficult to understand.

MATTSON: Do you think that we know so much more about the biological effects and human health effects associated with land disposal and deep well injection and consideration of atmospheric disposal that these are the options we should use?

PHELPS: We are addressing once again disposing of wastes in the ocean, and I am saying the problem concerning what we know or do not know about disposal in the ocean exists quite independently from what we may or may not have about aerial or the terrestrial disposal problems.

GOLDBERG: Let me ask you a question, Jim (Mattson). You will immediately see my bias. With respect to biological effects on communities of organisms, I submit that the marine people have done a much better job than terrestrial people. I would submit that the marine people have published more sophisticated information about this problem.

The next problem about the terrestrial versus the marine system--with respect to predicting capability, the hydraulic problems versus the ocean problems--in spite of what Gabe Csanady said, he was being very modest, I think the oceanographers know much more about the plumbing in the marine system than the hydrologists know about the land system. I am deeply concerned about impact upon subterranean waters by land disposal, much more than I am about marine disposal.

I drink fresh water. I do not drink seawater.

SEGAR: I would like to reinforce that. With the risk analysis we are doing in the New York City sludge case, certainly what we are trying to do now is compare the land-based alternative to the ocean-based alternatives and in calculating the human health risks, which is the primary thing we are focusing on, there is certainly a much greater lack of information for the land-based alternatives in Greater New York than there is for the ocean-based alternatives.

MATTSON: If I could just follow up on that. The route to man is so much shorter with some of the land alternatives that people who have been promoting for ten years--and I refer to them as the know nothings --that we know nothing about what happens to pollutants in the marine environment. They are really disregarding the corollary to that, which is: we do not know a thing about what happens in the atmospheric environment or the land environment either. So to say that we should not put it in the ocean because we do not know anything about it and to imply, therefore, that it should go on land is the wrong way to go

about it. What they are really arguing is whether you should contain and not disperse. Someday, when we learn what we have done in the aquifers and to land, we will dig it up and disperse it.

CSANADY: To quote specific examples that one can bring up from the Crystal Mountain report, we were discussing the Dump Site 106 situation. A lot of chemical wastes have been dumped there without any obvious ill effects, and there is no reason to believe that there were any.

You can think of the Love Canal story. If that stuff had been dumped at 106, we probably would have never heard anything about it.

BIVENS: You talked a lot about effects on individuals and I wonder what you think of the idea of looking at the larger ecosystem in the sense of looking at plankton populations and that sort of thing from a species diversity point of view. The reason I ask that question is because I am not a biologist; I am an engineer. I have been involved in the last couple of years with fisheries in looking at techniques of plankton analysis and that sort of thing. It looks like in the next ten years or so there are going to be a lot of new techniques for looking at samples rapidly, lots of them and get a real statistical base. I recall reading an article by John Gray* where he talked about looking at ecosystems, looking at log-normal distributions, and as you pass through pollution gradients, for example, you no longer see log-normal distribution. It seems like a limitation in getting the statistical distributions. You might be able to do that in the future. I wondered what you thought of that?

PHELPS: My sense of what has been done in the past is that results, when they are available, are simply out of synchrony with time and location of exposure. It is very difficult to establish cause and effect relationships on the question of diseased populations of fish and specific types or locations of pollutants, for example. I do think that long-term monitoring for a useable data base should be carried out.

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RADIOACTIVE WASTE DISPOSAL IN THE MARINE ENVIRONMENT

by

Daniel R. Anderson*

Abstract

In order to find the optimal solution to waste disposal problems, it is necessary to make comparisons between disposal media. Historically, chemical waste disposal has been in a single medium, whether air, land, or water, depending on what was easiest or, more recently, least regulated by the Environmental Protection Agency (EPA). During the last several years, it has become obvious to many within the scientific community that this single-medium approach leads to over-protection of one medium at the expense of the others. Cross-media comparisons are being conducted in the Department of Energy's ocean disposal programs for several radioactive wastes. Investigations in three areas address: (1) model development, (2) comparisons of laboratory tests with field results and predictions, and (3) research needs in marine disposal of radioactive waste.

Probably the first question that crosses your mind is, "Why is an oceanographic program being managed out of Sandia National Laboratories in the middle of the New Mexican desert?" Part of the answer was given by one of the previous speakers: "The two oceans are different." In addition, the oceanographers who study those two oceans are different, and are very biased as to which ocean is the "best." Sandia is a neutral ground. The thoughts that I present today are a summary from the principal investigators of the Subseabed Disposal Program, representing both oceans.

The next question usually asked is, "Why look at the oceans at all for any kind of nuclear waste disposal?" The Department of Energy (DOE) said that if we are going to look for the best geologic option on planet Earth, we ought not to forget the 70 to 80 percent of the globe covered by water. Another consideration is what other nations, such as Japan and to some extent England, can do when they do not have any good land-based geologic formations. These nations will use the

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ocean for disposal of some types of radioactive waste. The U.S. and DOE must know enough so that their programs can be assessed, and if those programs turned out to be scientifically or environmentally infeasible, they could be discouraged. We have done this with England, which initially wanted to put high-level waste on the bottom of the ocean.

To turn our thoughts to the subject of ocean dumping, many of us have forgotten that the oceans have been nature's garbage dump for many materials from the beginning of time. The mountains erode, are carried out to the oceans by rivers, and are deposited on the ocean floor as sediment. Any heavy metals such as mercury or lead and natural radionuclides such as potassium-40 will go into the ocean waters. The oceans and the animals in them have developed a capability of handling those wastes. However, for other materials, such as polyethylene and PCB's, the ocean has not developed that capability.

Next, I would like to spend just a minute on philosophy. Shortly, before his death, John D. Isaacs wrote: "Perhaps the most important relationship of the ocean to human power needs in the future will be employment of the d' ep regions below the seafloor for disposal of nuclear waste."

A review of the fields of chemical waste, sewage sludge, and to some extent radioactive waste, shows that for any waste generated by man there are three places to put it: the land, the air, and the water. EPA, and to some extent, Congress as well, has developed a methodology that I will call the "pet environment" syndrome, wherein a part of the agency says that we are going to protect that environment (in this case the ocean) at all costs. The results have been that disposal of wastes has been moved from one medium to another without logical reason. The medium of choice then is usually the one which has the least regulations applied to it rather than whether it is the optimal medium of dispose of that waste. Several of the speakers have mentioned that in their talks today, but I really want to make this point very strongly. I would suggest to EPA and to Congress, too, that they reconsider the problem of waste disposal and the environment; that they try to get rid of the "pet environment" syndrome and develop a unified approach to waste disposal.

Now for the rest of the time, let's talk about the disposal of nuclear waste in the oceans. Table 1 illustrates the makeup of high-level waste. As you can see, almost fission products (the first group in the table) decay in about 1,000 years. Containment of these fission products for 1,000 years renders them non-radioactive. If you look at the transuranics (the second group in the table), you see they decay in 10^4 to 10^7 years. The transuranics are the longer-lived radionuclides that people worry about. However, they are not necessarily more dangerous than the fission products.

BASIS: 378 LITER/MTHM, 25 GWD/MTHM, 35 MW/MTHM,
SGR = 1.0 FOR MOX CONTENT;[3)] No Xe, Kr, 0.1% I, Br,
10% ^3H,[b)] 0.5% Pu, 0.5% U, ALL Np, Am, Cm

	g/LITER	Ci/LITER		THERMAL W/LITER	
FISSION PRODUCTS	5 Y	1 Y	10 Y	1 Y	10 Y
^3H[b, h)]	11E-6[M]	0.13	0.08	-	-
Rb	0.8	-	-	-	-
Sr	1.5	140	110	0.16	0.13
Y	0.86	150	110	0.80	0.62
Zr	7.0	17	-	0.08	-
Nb		38	-	0.18	-
Mo	6.9	-	-	-	-
Tc	1.7	0.03	0.03	-	-
Ru	4.5	540	1.1	0.03	-
Rh	1.1	540	1.1	5.30	0.01
Pd	3.1	-	-	-	-
Ag	0.16	52	-	0.38	-
Cd	0.18	0.07	0.04	-	-
Sn	0.11	0.83	-	-	-
Sb	0.03	16.8	1.7	0.05	-
Te	1	7.2	0.42	-	-
Cs	5.4	470	190	2.80	0.31
Ba	3.3	200	160	0.80	0.65
La	2.5	-	-	-	-
Ce	4.8	820	0.3	0.54	-
Pr	2.3	830	0.3	6.29	-
Nd	8.0	-	-	-	-
Pm	0.08	210	19.5	0.08	-
Sm	1.8	2.9	2.7	-	-
Eu	0.3	21.7	9.7	0.16	0.08
Gd	0.2	-	-	-	-
TOTAL F.P.[f)]	57.75	4074	614.6	17.7	1.81
ACTINIDES					
U	12.65	-	-	-	-
Np	0.674	0.36	0.36	-	-
Pu	0.4	3.96	3.03	0.03	0.03
Am	2.3	2.07	2.07	0.06	0.06
Cm	9.65	99.7	45.8	3.56	1.60
TOTAL ACT.[f)]	16.79	106.2	51.3	3.65	1.69
TOTAL	74.5	4180	664	21.35	3.50
CHEMICALS					
HNO_3[i]	126	-	-	-	-
Gd	23.8	-	-	-	-
PO_4^{---}[j]	4	-	-	-	-
Fe	3	-	-	-	-
Cr	0.5	-	-	-	-
Ni	0.2	-	-	-	-
Na[j)]	0.1	-	-	-	-

Table 1. Composition of Liquid High-Level Waste[d]

In addition to these two categories, you have the noble gases, which do not remain in the liquid when fuel is reprocessed. During the processing of fuel and vitrification of the waste, the gases, carbon-14, iodine, and some of the technitiums are captured by the air scrubbers and must be treated separately. (A point for now, to be clarified later in the presentation, is that all the radionuclides listed in the table except technitium are positively charged.) I would like to emphasize that not only do you have to look at the medium, you also have to consider the waste radionuclides as well. For example, strontium: obviously, it must be contained until it has decayed to background. On the other hand, there is no way of containing iodine, which has about a 17-million-year half-life. (Even mountain ranges have lifetimes of less than ten half-lives of iodine--the time required for the radionuclides to decay to background.) Even if you could bury it in a mountain, it would still get out into the environment. The best method of handling iodine, therefore, should be to disperse and isotopically dilute it, rather than contain it.

As I indicated earlier, there is already much radioactivity in the ocean. In Figure 2, let us focus on two examples. First, potassium-40: there are about 10^{11} curies in the ocean. With a half-life of 10^9 years, it has been and is going to be around for a long time. Second, radon and radium: they have short half-lives but are constantly being replenished by release from the bottom. Thus, again the system (all organisms) is in equilibrium.

Let us focus down from the size of an ocean to something more comprehensible; for example, a circular area of 60-meter radius in water 5 kilometers deep. In this volume, there are two curies of potassium-40 in the water column, and 0.03 to 0.1 curies per year of radon coming out of the sediments. Using this as background data, let me give you an example of an unacceptable situation existing right now in our waste disposal program. In a site in Middlesex, New Jersey, there are 100,000 cubic yards of dirt. This dirt contains four curies of radium and radon. If that dirt was spread out on the bottom of the ocean so that it would just double the amount of radium/radon oozing out of the sediment, it would require an area of about 40 football fields. The natural variation of radium/radon release from the sediment is about ten; thus a doubling will have minimum impact.

Earlier, Dr. Goldberg said that cost is an important factor. If, for example, I dispose of that pile of dirt, which is contaminated by natural radionuclides, in a landfill developed for low-level radioactive waste, it will cost somewhere between $50 million and $80 million. On the other hand, if that dirt is dispersed, or put in an old ore carrier and sunk, it will cost between $3 million and $5 million. Should not we consider costs as one part of the decision equation?

CONCENTRATIONS OF SOME NATURAL RADIONUCLIDES IN THE SEA

Radionuclide	Half-Life	In Seawater (dpm/liter)	World Ocean Volume	Radioactivity In The World Ocean	
	(Terrigenous Origin)				
^{40}K	1.25×10^9 y	670	$1.37 \times 10^{21}\ell$	9.18×10^{21} dpm	(4.1×10^{11} Ci)
^{87}Rb	4.7×10^{10} y	64	$1.37 \times 10^{21}\ell$	8.87×10^{22} dpm	(3.99×10^{10} Ci)
^{129}I	1.7×10^7 y	0.06	$1.37 \times 10^{21}\ell$	8.22×10^{19} dpm	(3.74×10^7 Ci)
^{210}Pb	19.4 y	0.2	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm	(1.25×10^8 Ci)
^{210}Bi	5.01 d	0.2	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm	(1.25×10^8 Ci)
^{210}Po	138.4 d	0.2	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm	(1.25×10^8 Ci)
^{222}Rn	3.8 d	0.2	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm	(1.25×10^8 Ci)
^{226}Ra	1622 y	0.2	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm	(1.25×10^8 Ci)
^{228}Ra	6.7 y	0.05	$1.37 \times 10^{21}\ell$	6.85×10^{19} dpm	(3.11×10^7 Ci)
^{228}Th	1.91 y	0.07	$1.37 \times 10^{21}\ell$	9.59×10^{19} dpm	(4.36×10^7 Ci)
^{234}Th	24.1 d	2.2	$1.37 \times 10^{21}\ell$	3.01×10^{21} dpm	(1.37×10^9 Ci)
^{234}U	2.48×10^5 y	2.3 – 2.9	$1.37 \times 10^{21}\ell$	3.15×10^{21} dpm – 3.97×10^{21} dpm	(1.43×10^9 Ci – 1.81×10^9 Ci)
^{235}U	7.13×10^8 y	0.09 – 0.17	$1.37 \times 10^{21}\ell$	1.23×10^{20} dpm – 2.33×10^{20} dpm	(5.6×10^7 Ci – 1.06×10^8 Ci)
^{238}U	4.5×10^9 y	2.0 – 2.5	$1.37 \times 10^{21}\ell$	2.74×10^{21} dpm – 3.43×10^{21} dpm	(1.25×10^9 Ci – 1.56×10^9 Ci)
	Cosmic Origin				
^{3}H	12.26 y	0.036	$1.37 \times 10^{21}\ell$	4.93×10^{19} dpm	(2.24×10^7 Ci)
^{7}Be	53 d	38	$1.37 \times 10^{21}\ell$	5.21×10^{22} dpm	(2.37×10^{10} Ci)
^{14}C	5,570 y	0.2 – 0.3	$1.37 \times 10^{21}\ell$	2.74×10^{20} dpm – 4.11×10^{20} dpm	(1.25×10^8 Ci – 1.87×10^8 Ci)

Figure 2. Concentrations of Some Natural Radionuclides in the Sea

Now, back to the underlying problem. The regulations or rather, the lack of coordinated regulations is driving some projects into some very unreasonable and costly positions. The research approach at the Department of Energy for all radioactive waste disposal assumes that containment for a long period of time is necessary. Thus, in order to understand and demonstrate long-term containment, a set of models will be developed for predicting responses (Figure 3). After obtaining the properties, predictions are made. These predictions are then verified in the field. Finally, the model sections are coupled to produce a system model which will allow an estimate of the performance of the repository (Figure 4).

During the remainder of my talk, I will cover the left half of Figure 4, and Dr. Dexter will discuss the right half. The left half of Figure 4 is detailed in Figures 5-15.

On my side, the first section is the thermally driven interactions (Figures 5 and 6). For a canister that is one foot in diameter and 10 feet long and contains waste releasing 1.5 kilowatts of power placed in the sediments, the heat moves out through the sediments by conduction. The temperature of the canister/sediment interface will be 200-500°C. At this temperature, the water in the surrounding sediment heats up, magnesium precipitates as magnesium hydroxide sulfate, and the pH changes from eight to about three. With time, of course, the pH builds back up (Figure 7).

What else happens when you put this canister down in the sediment? It irradiates the water, and you get a highly oxidizing environment. The radiation does not damage the sediment particles themselves. Neither does the heat. The main changes that occur are the pH changes and the increased oxidation of the water.

When radionuclides are released into the sediments, they move through these sediments by diffusion only. For all of the positively charged radionuclides--and I am using erbium as an example--you get a high sticking factor (distribution coefficient). The sticking factor increases with temperature and decreases with concentration (Figure 8). Our calculations, using the IONMIG model and measured sticking factor for plutonium, show (Figure 9) that the plutonium never reaches the surface.

For the water column, we are preparing a group of models which address many aspects of physical oceanography, biology, dose to man, and the effects on the local biota (Figure 10). These models include source models, a regional model, layered midwater models, a regional surface model, and a basin model (Figure 11). (These models can also be used for chemicals, heavy metals disposal problems, and so on.)

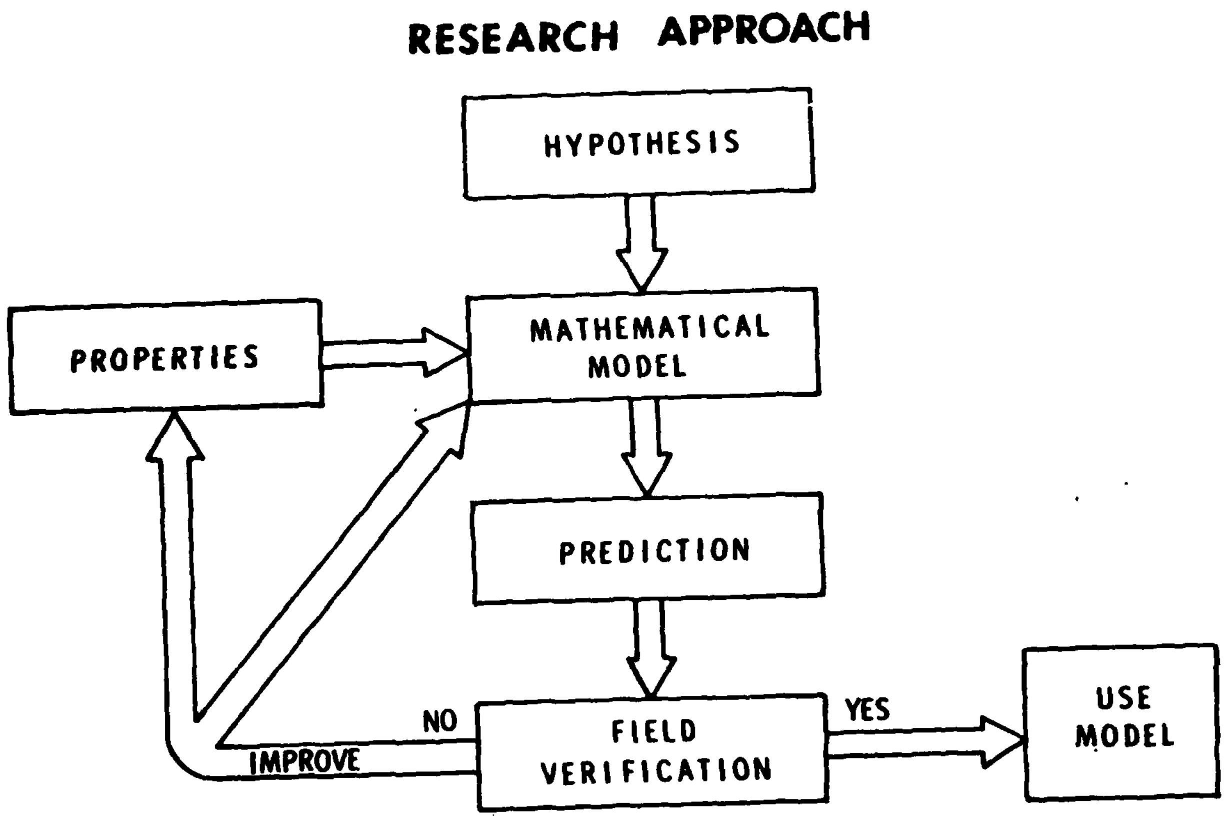


Figure 3. Research Approach

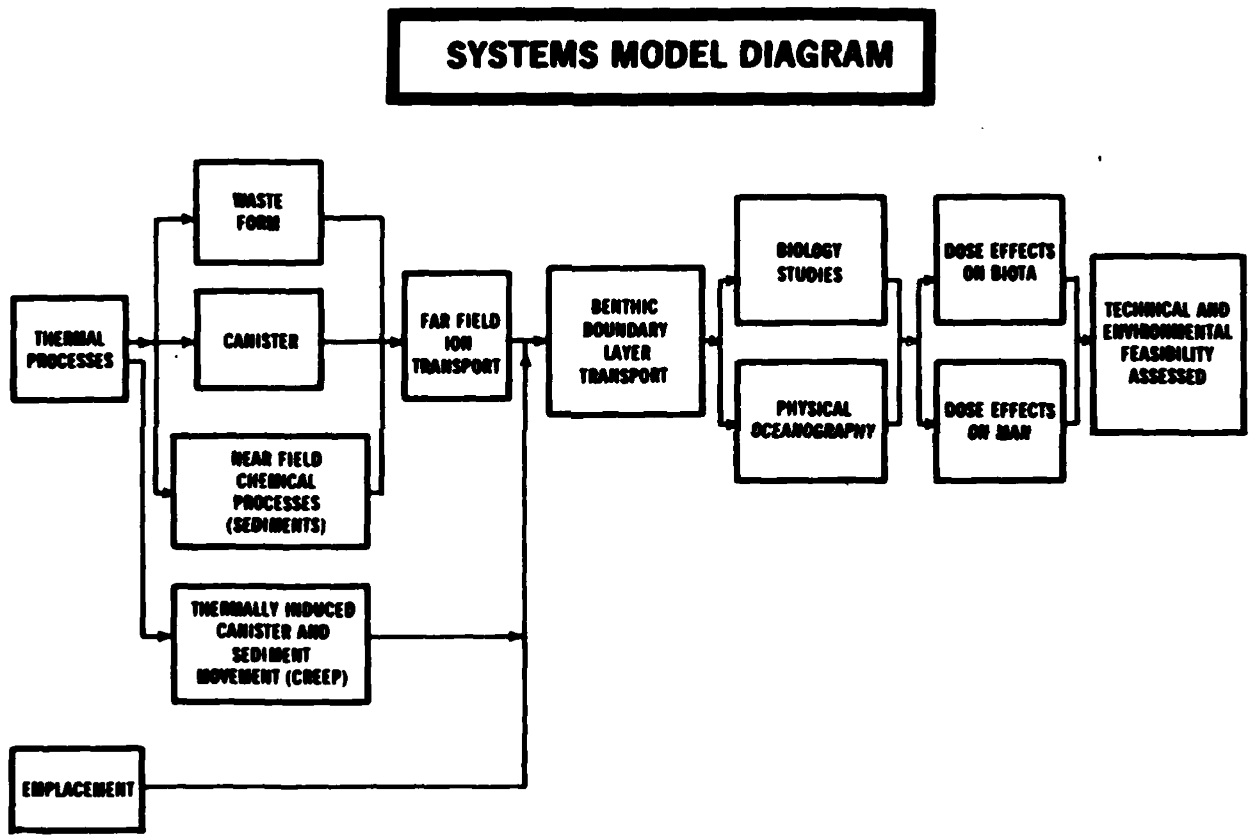


Figure 4. Systems Model Diagram

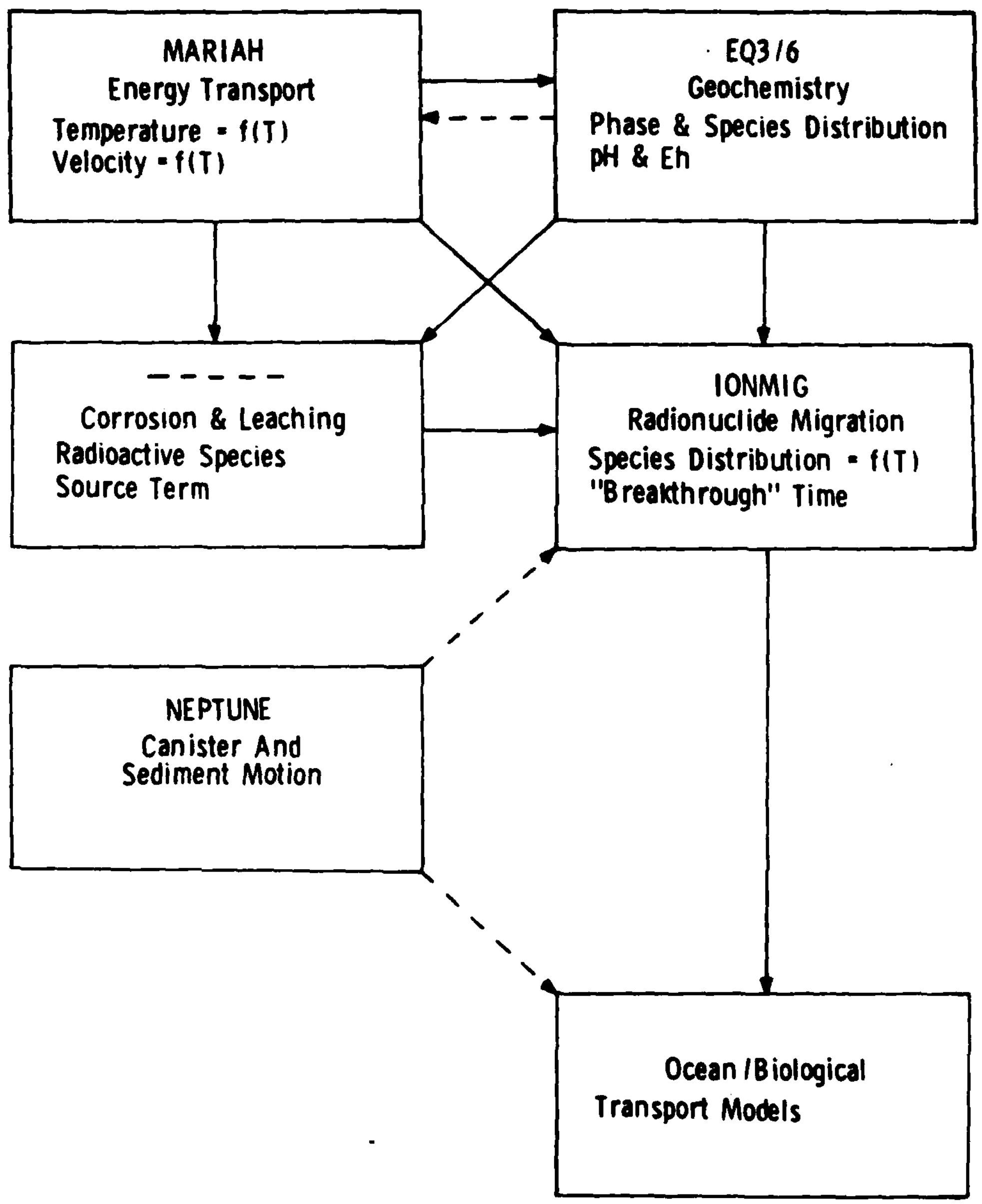
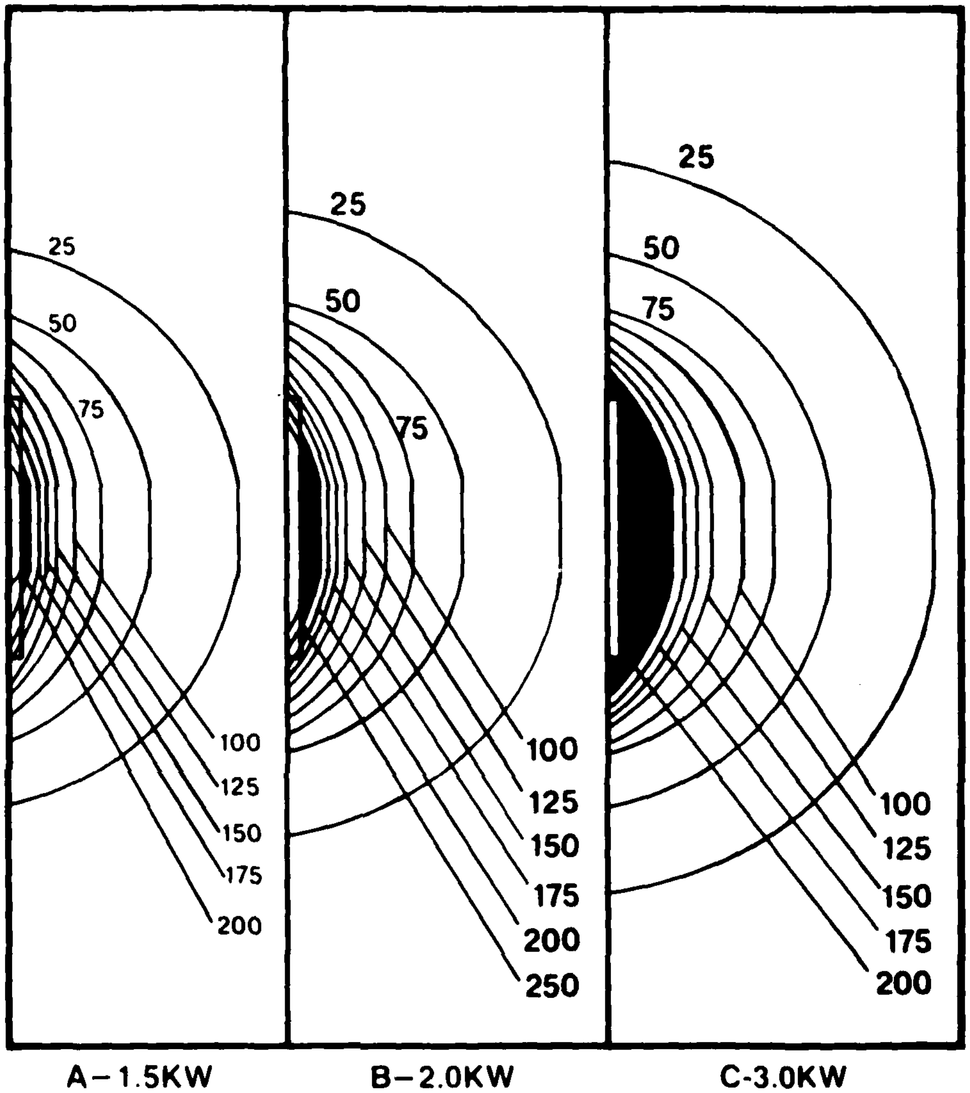


Figure 5. Thermally Driven Interactions



ISOTHERM PLOTS SHOWING MAXIMUM PENETRATION OF 200°C ISOTHERM INTO SEDIMENT

Figure 2

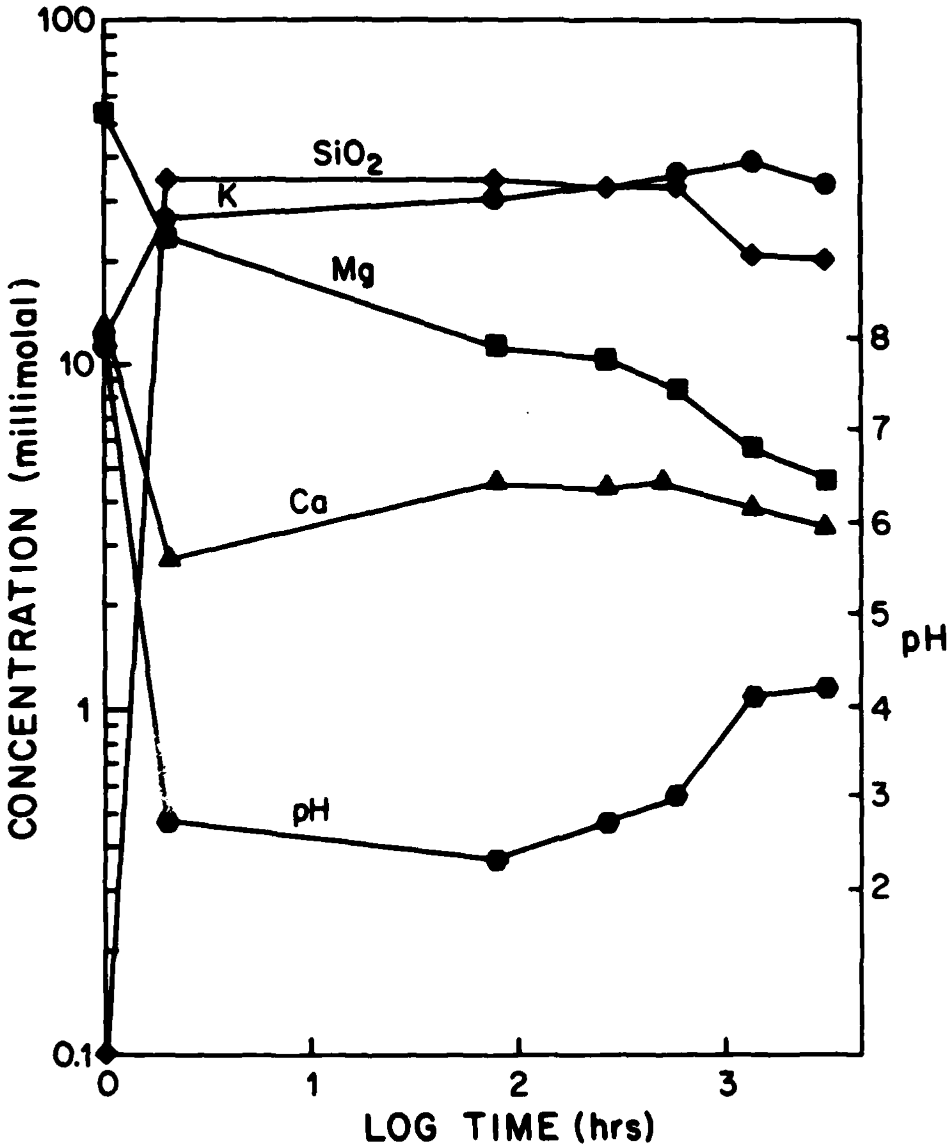


Figure 7. Concentrations and PH Changes in Heated Sediments

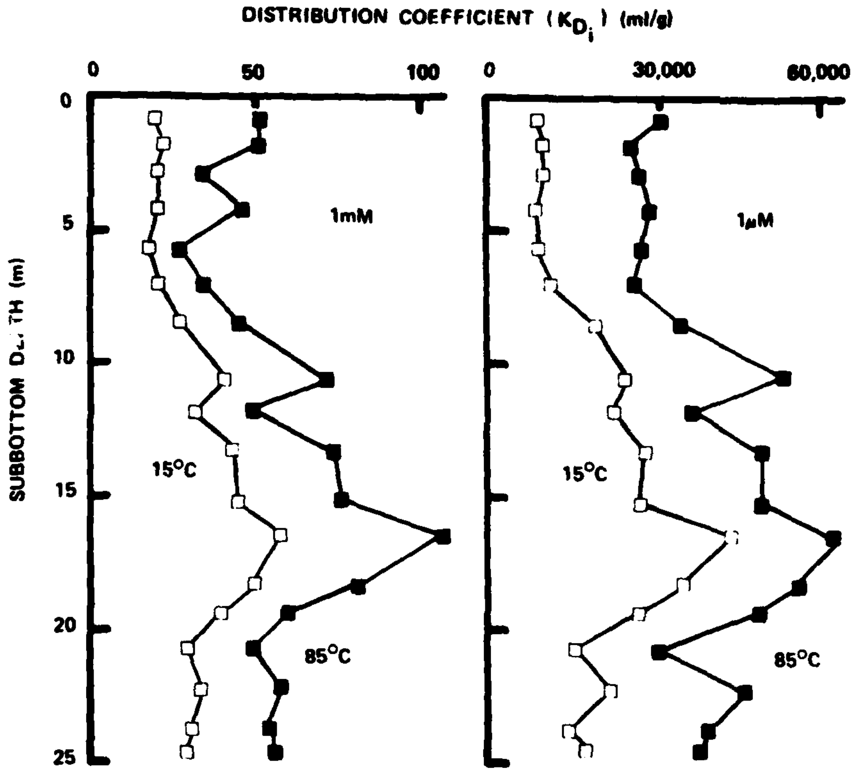


Figure 8. Downcore Variation in Distribution Coefficient of Bu for Two Concentrations in 0.68N NaCl in Sediment from Core LI44-GPC3 (from MPC-1)

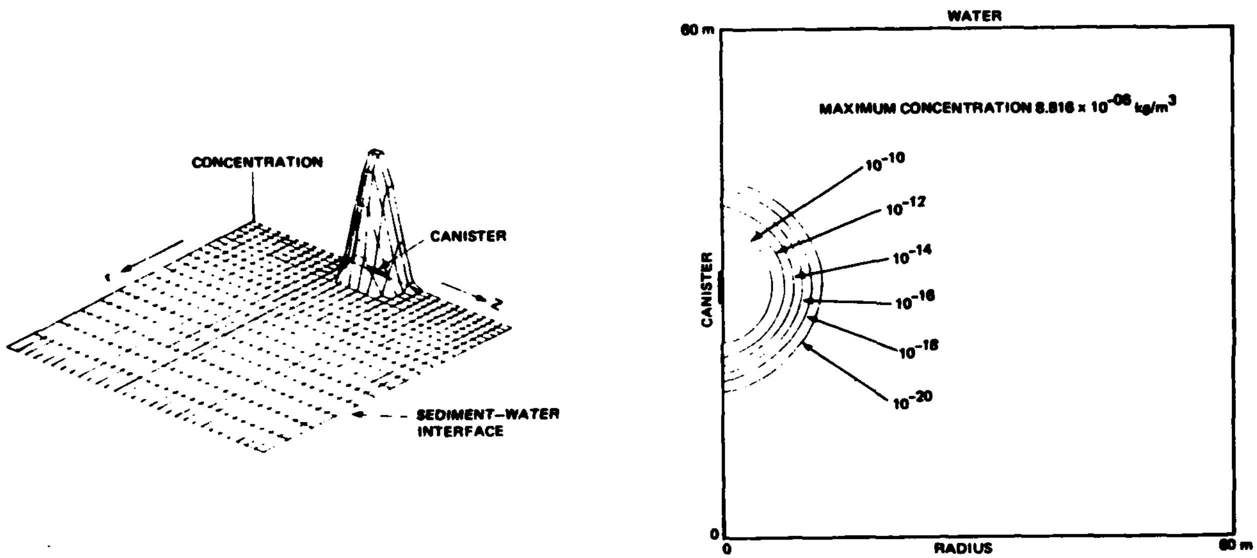


Figure 9. Plutonium Concentration in the Sediment at 100,000 Years

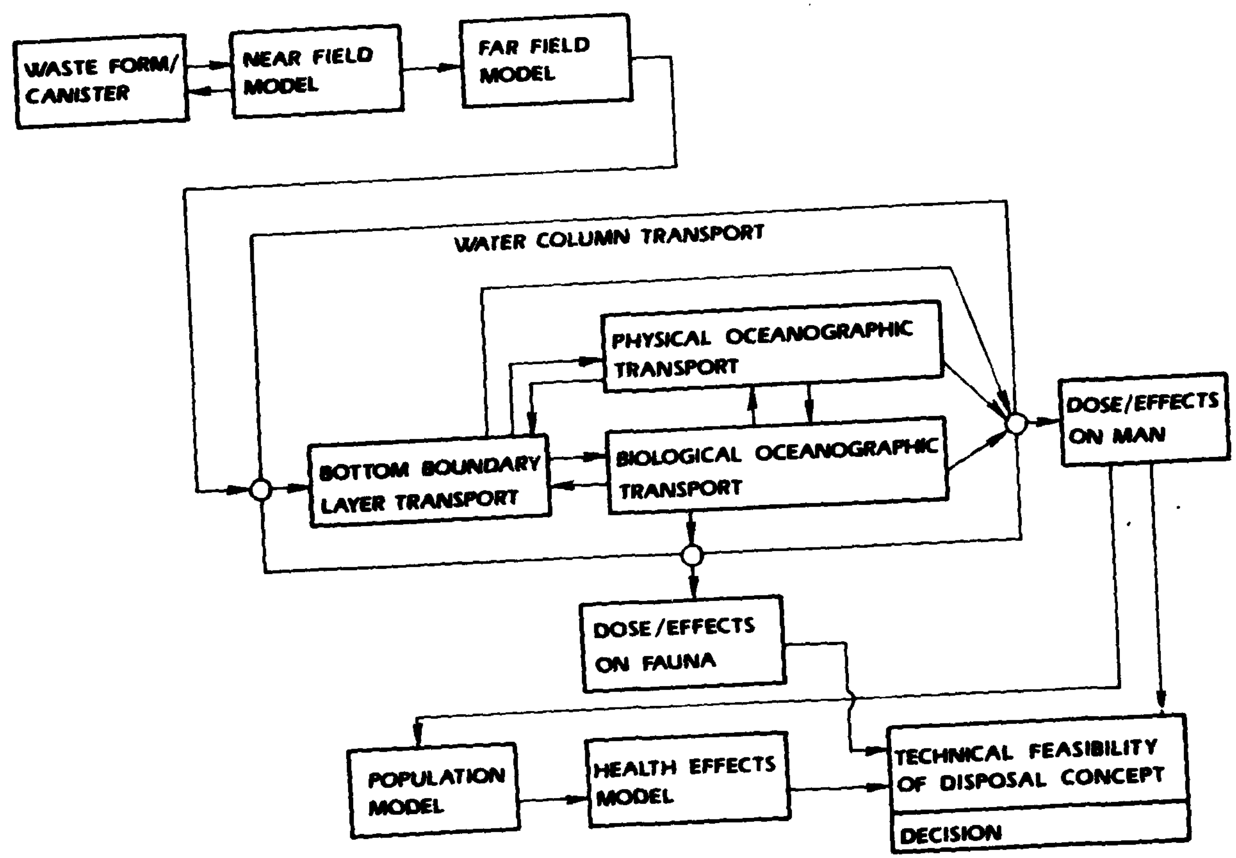


Figure 10. Ion Transport Analysis Model

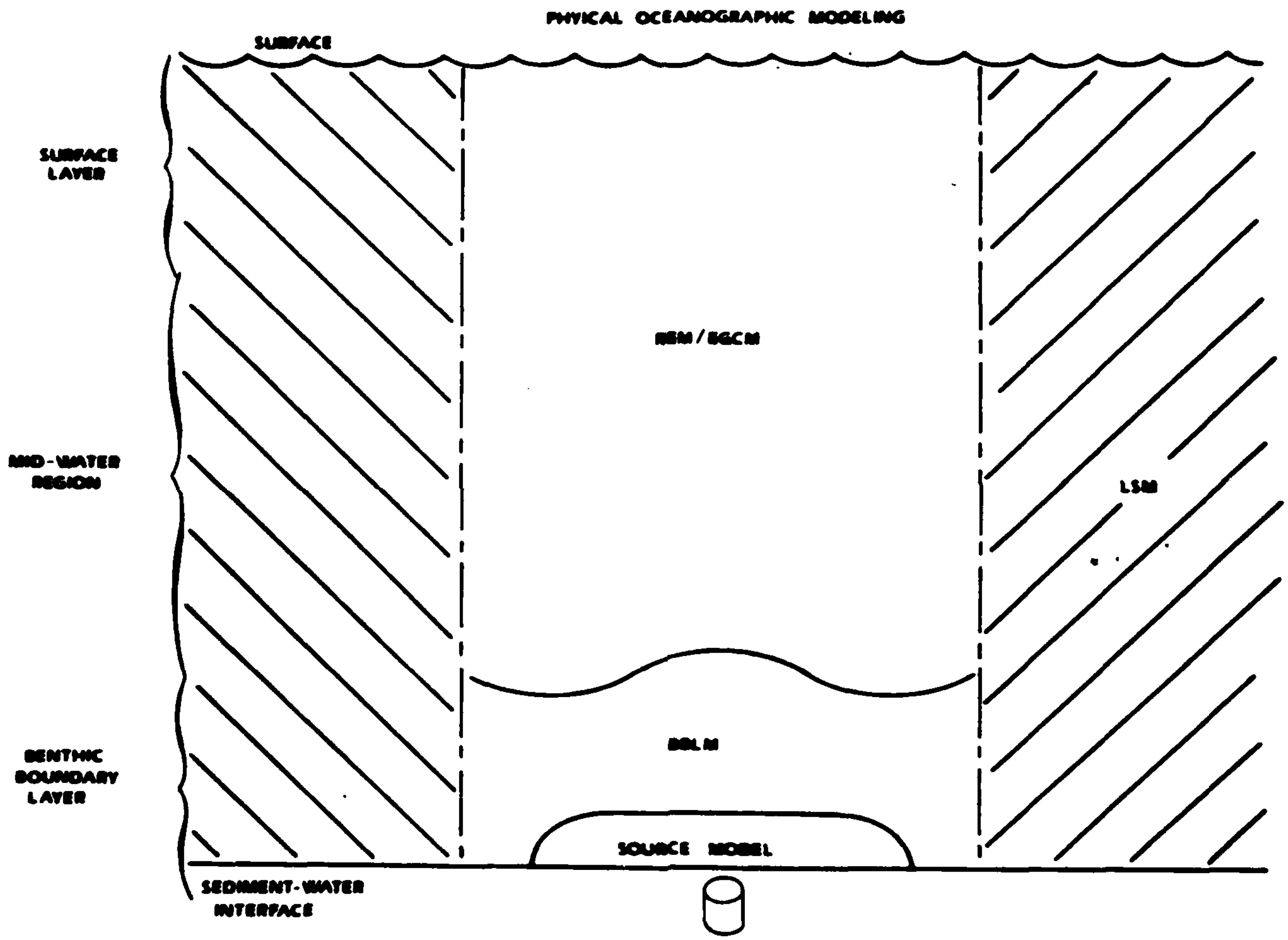


Figure 11. A Hierarchy of Models Relevant to the Waste Disposal Problem

Where are we in all of this development process? By the end of 1982, the sensitivity analyses will be completed on all of these models. What does the sensitivity analysis do? For example, in the benthic boundary layer model (BBLM), the analysis (Figure 12), will tell you where to put your money for your research, i.e., which parameters are important, and thus should be studied in detail. Ed Goldberg, your comment was correct. We are often doing the wrong research because we do not know what we need to do. This model sensitivity analysis sequence is one way, assuming you have the correct model, to direct your research very carefully. For example, within the BBLM, I would put my money on the time-varying driving current rather then on density measurements. The better and more complete the models are, the more research can be directed.

We are doing some field physical oceanography work, as well. Figure 13 depicts some data from Dr. Vaughn Bowen of Woods Hole Oceanographic Institution. These data on plutonium concentrations in the Pacific Ocean will be used as a test case for the physical oceanography models.

The structure of the biology models include the infauna, the swimmers that go between, the epifauna that go along the bottom, and of course the surface species (Figure 14). Field work includes a batch camera to record how fast amphipods come to food.

In conclusion, we have developed or are developing a lot of new tools that will allow us to assess environmental impacts of waste disposal programs in the oceans. We are also drastically expanding the data that we have (Figure 15). I also think EPA was right in the past when they said that we do not know enough about the oceans to use them as either a radioactive or chemical dump. However, in light of our new knowledge, the disposal issue should be reconsidered.

ENVIRONMENTAL STUDIES MODELING

MODEL	ACQUIRE	MAKE OPERATIONAL	MODIFY FOR SDP	BENCH MARK	UPGRADE	SENSITIVITY ANALYSIS	TEST CASE	FIELD VERIFICATION		PRELIMINARY INTERFACING
								NON-SITE	SITE	
BBL (1D)					YES					83
BBL (3D)	DEVELOP IN HOUSE			82		82	83	83	95	83
REM/EGCM (ONE LAYER)			81	81	YES	81	81	82		83
REM/EGCM (MULTI-LAYER)	81	81	82	82		82	82	83	95	83
LSM			81	81		82	83	83		83
ECOM	DEVELOP IN HOUSE					82			95	83

COMPLETE

PARTIALLY COMPLETE

NOT REQUIRED

APPROPRIATE DATA BASE NOT YET IDENTIFIED

Figure 12. Environmental Studies Modeling

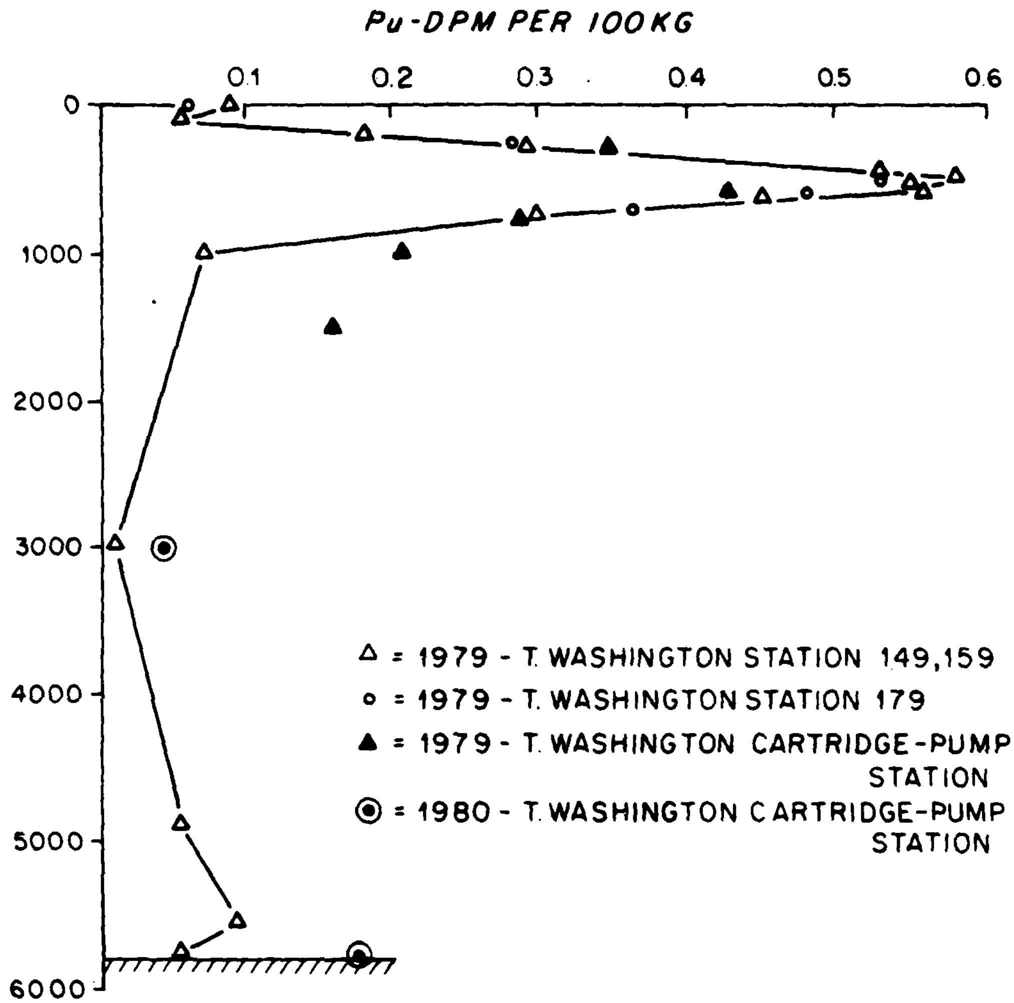


Figure 13. N. Pacific Profiles - LVS vs Cartridges

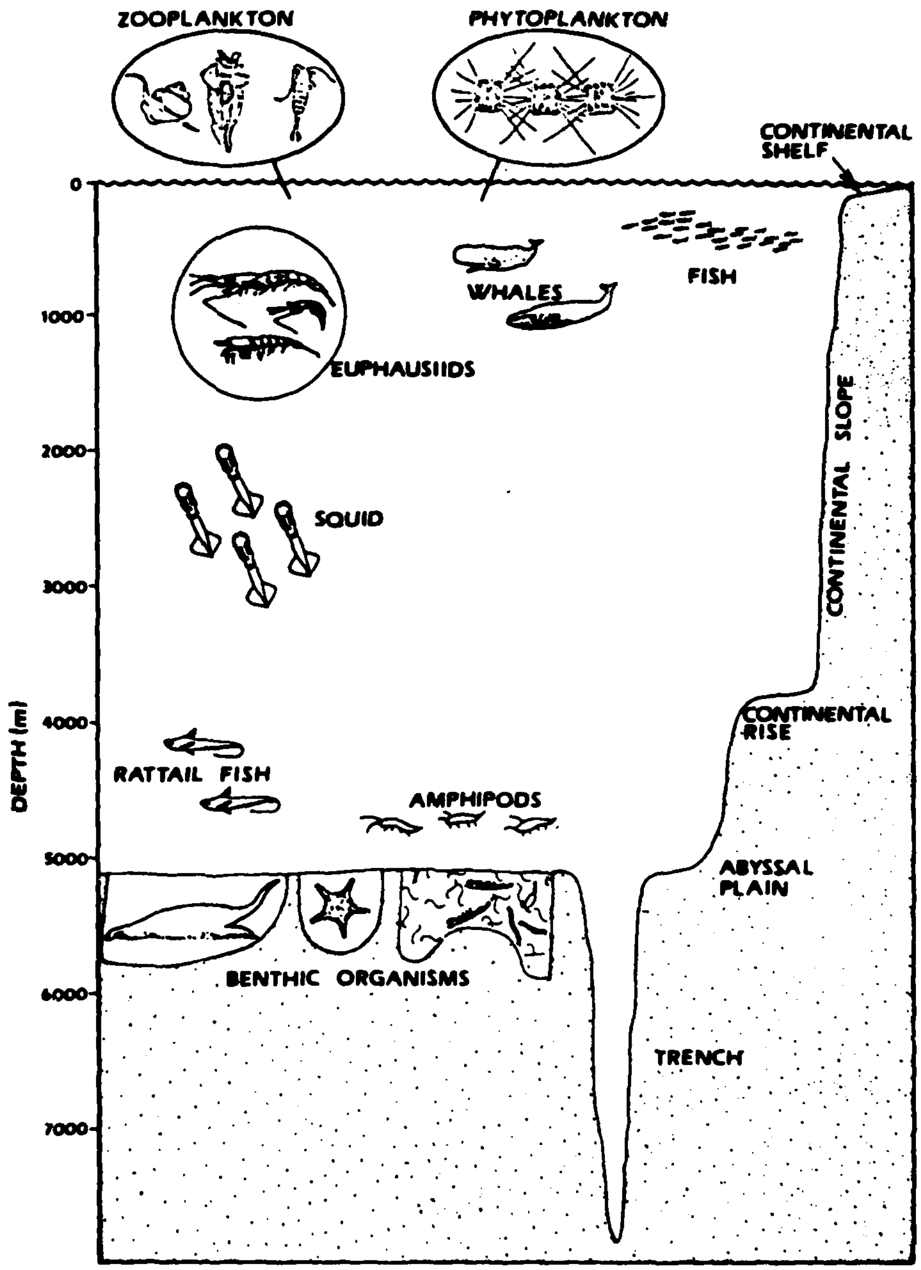


Figure 14. Representative Marine Biota (not drawn to scale)

	Earth Science	Biological Oceanography	Physical Oceanography	Thermal	Near Field Chemical	Far Field Chemical	Mechanical	Waste Package	Emplacement	Transportation	Regulatory & Institutional	Systems Analysis
Models	X	A	A	X	A	X	X	A	A	A	A	A
Properties Estimated	X	A	A	X	A	X	X	A	A	O	A	A
Properties Acquired	A	A	A	X	A	A	A	A	O	O	A	A
Field/Lab. Verification	O	O	O	A	A	A	A	O	O	O	O	O

End of Phase 2

A – Active
X – Complete
O – Not Yet Initiated

Figure 15. Subseabed Disposal Program Scientific/Environmental Feasibility Matrix

PACKAGING OF RADIOLOGICAL WASTE: MATERIALS AND OPTIONS

by

Stephen C. Dexter*

Abstract

For radiological wastes, which by their nature become less dangerous with the passage of time, it is shown that the questions: (a) how much can the ocean assimilate, (b) how should we (or even should we) package various wastes for ocean disposal, and (c) how much are we willing to pay for a containment system and what performance is to be expected, are all closely linked together. In the one extreme, there may either be no package at all, or the package may be designed only for safe transportation and delivery to the disposal site, the package then being allowed to disintegrate over a small fraction of the total time period over which the waste must be isolated from the environment and food chain. In the other extreme, the package may be designed to maintain its integrity and isolate the waste for the full time interval over which the waste is toxic. In the former case, the marine sediments and benthic boundary layer are asked to assimilate all the waste that is deposited in them. In the latter case, however, the package isolates the waste, and the ocean is asked to assimilate very little or nothing.

The above two options, as well as the intermediate one of partial containment, are examined in terms of the character of the waste involved, the materials systems available for containment, and their cost and performance.

Ladies and gentlemen, in the few minutes that I have with you today, I would like to focus our attention on containers themselves. What options do we have for packaging various waste forms for which the ocean might be considered a final repository? I want to make several simple points this afternoon. Perhaps the most important one is that I believe the assimilative capacity of the ocean for a given waste form is directly related to the performance of the package in which that waste is delivered to the ocean.

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Three questions need to be answered. How much can the ocean assimilate? Should we package the waste? And if so, how? What will the container cost and what performance can we expect? Those three questions are all linked together. How much waste you can introduce depends upon how you do it. So, we have a system, very simplified, of water, container, and sediments. The container may be at the water-sediment interface, but that may not always be the case. For instance, in the case of high-level waste, the container would almost certainly be buried. But, in any case, the container should be considered as part of the system.

If under an appropriate set of conditions, the container can be engineered to function well enough for long enough, then we may, in fact, be asking the other components of the system, the water and the sediments, to assimilate very little or nothing at all. The container as one part of the system can be asked to perform one of three functions: (1) transportation to the disposal site only; (2) transportation plus temporary containment; or (3) long-term isolation of the waste from the environment and the food chain.

How do we decide which of these functions is appropriate for a given waste form? The first step is to recognize that all structural materials from which we could build a canister have finite lifetimes in seawater. There is no such thing as a cheap, readily available structural material that has an infinite lifetime. If there were, we could package everything. The second step is to examine the character of the waste itself. I have divided wastes into three (perhaps oversimplified) categories: wastes that biodegrade; chemical and other waste forms that do not change with time; and wastes that become less dangerous with time. Certainly, for wastes that biodegrade, you do not want to isolate them from seawater with a package, and some of these waste forms may, in fact, also be beneficial, as we have heard.

For wastes that do not change with time, containment is probably pointless. Since the container life is far shorter than that of the waste, you are merely postponing the inevitable by attempting to contain it. Packaging, however, can be a desirable thing to do for the third category where the wastes become less dangerous with time. High- and low-level radiological wastes fit into that category. So, let us take a closer look at what is meant by those two terms. Low-level wastes are defined as having gamma and beta emitters with half lives less than about 30 years, ambient temperatures, less than 10 nanocuries of alpha emitters per gram, and a desired isolation period of 50 to 300 years. High-level wastes, in contrast, have high concentrations of gamma and beta emitters, temperatures at the container wall of 200°C to 300°C for up to 600 years, high concentrations of alpha emitters with half lives greater than 10^5 years and desired isolation periods of: (a) 600 to 1,000 years for the heat generating gamma and beta emitters to decay to harmless levels, and (b) more than 10^6 years for the alpha emitters. I would put the alpha emitting

wastes into the category that do not change with time. It is relatively pointless to attempt to contain these wastes because we just do not have materials that will last long enough.

Let us now turn our attention to the container materials themselves. A well-engineered container must have the following characteristics: (1) it must be chemically compatible with the waste stream, and any transmutation products of the radiolysis; (2) it must have long-term resistance to corrosion in seawater at up to 300°C including general corrosion, localized corrosion, and stress-aided forms of corrosion; (3) it must have adequate resistance to radiation damage; (4) it must have adequate mechanical strength to withstand transportation, hydrostatic pressure and seismic activity; (5) it must be compatible with the welding process used to seal up the container; and (6) it must be reasonable in cost.

A large number of materials have been screened to see whether or not they meet these characteristics. Much of this work has been done at Sandia laboratories by Dr. Anderson's colleagues in their seabed program. Other data on behavior of materials in elevated-temperature seawater environments have come from people working in desalination and geothermal energy facilities.

A great deal of this data is summarized in Table 1. Many more materials have been considered, but the choices have been narrowed down to those shown in the Table. The corrosion rates are indicated in column 2, and rate increase caused by gamma radiation is indicated in column 3. The large rate increase for mild steel is related to the production of oxidizing agents that Dr. Anderson mentioned.

The relative cost of these materials compared to that of commercial purity titanium is shown in column 4 of Table 1, page 78. This column gives the cost per year of canister life or per year of containment over a 300-year lifetime. For a one-year containment period, titanium is the most expensive material. Over the long term, however, a steel container would have to be so heavy and thick to accommodate the corrosion rate, that it would become more expensive by a factor of 900. Such a steel container would also be difficult to handle at sea.

The advantage of Ti Code 12 over commercial purity titanium comes in the form of an increased resistance to pitting and crevice corrosion to which pure titanium is susceptible at elevated temperatures. For low-level waste, where the temperatures are nearly ambient, commercial purity titanium is quite adequate but for high-level waste, the Ti Code has a distinct advantage.

All of these materials would be used in what is referred to as the multibarrier concept. This means that various layers of the container, plus the geologic repository, present several successive

barriers to dispersal of the radionuclides. This is illustrated schematically for low-level waste in Figure 1. Here the waste form itself is solidified either with some glass or ceramic matrix or concrete. The first barrier then might be unalloyed titanium, or for high-level waste the Ti Code 12. Then there might be another barrier of concrete outside of that; perhaps it could be one of the new polymer impregnated concretes on which the civil engineering laboratory in Port Hueneme, California, is working. These are far less permeable to water than normal concretes. To aid in shipboard handling and to avoid impact damage to concrete which is a brittle material, you might have on the outside surface a polymeric foam layer. For high-level waste with a high container-wall temperature, the foam might be of no use, but for low-level waste it certainly would be. The geologic repository is the final and ultimate barrier on the outside of the container, and such a container as this is far more sophisticated than the containers in which low-level waste has previously been dumped in the ocean.

Several years ago a low-level waste container was recovered in an EPA-sponsored project by the Research Submersible Alvin out of Woods Hole and the R/V Cape Henlopen out of the University of Delaware. The container was just an 80- or 55-gallon steel oil drum which was filled with concrete. If the waste was a liquid, it was used to mix the concrete. If the waste was a solid, it was imbedded in the concrete, in the interior, but there was nothing very sophisticated about it. The steel drum of the container recovered in the summer of 1976, was in remarkably good shape. That drum was not designed to be put in the ocean, but it did not really matter what happened to the drum. It was, in fact, "a baggy." It was just used as a mold for the concrete. Some corrosion did take place on the drum, but it was really inconsequential to the mission of the package.

Let us consider four cases. First, for low-level wastes, with radionuclides having half lines of five years or less, we could presently design a canister system to isolate the waste from the environment and food chain for the necessary 50-year period with a high level of confidence. I say this because we have experience with concrete since the days of the Greeks and the Romans (2,000 years ago or so). We also have 20 to 40 years of continuous seawater immersion data for titanium alloys, and that is getting pretty close to 50 years. So we are comfortable in designing a container for that period.

Second, when it comes to low-level wastes with radionuclides having half lives of about 30 years, necessitating an isolation period of 300 years, our confidence level begins to go down. We could design a container that we believe would do pretty well, but how do you prove a 300-year container without doing 300-year tests? No one can afford to wait that long to make a decision on handling nuclear waste, so there is just no way we can guarantee the performance of a 300-year container.

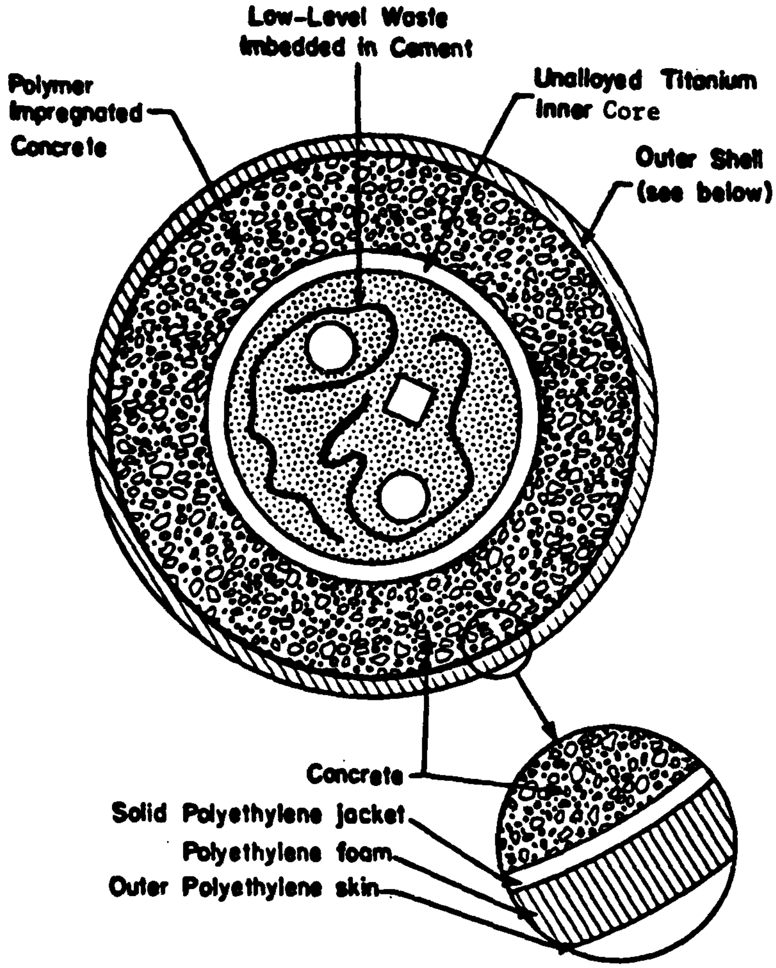

Figure 1. Schematic Cross-section of a Proposed Low-Level Nuclear Waste Container. (Used with permission from: Stephen C. Dexter, Materials for Containment of Low-Level Nuclear Waste in the Deep Ocean, U.S. Environmental Protection Agency, Office of Radiation Programs, Technical Note: ORP/SEPD-80-1, 1978, Washington, D.C.)

Third, when it comes to high-level waste, we first have the 600- to 1,000-year thermal period. If we can isolate the waste over that thermal period, we will have isolated the most dangerous, the most penetrating and heat generating radionuclides until they have decayed away and the temperature has returned to near ambient. That is certainly a worthwhile goal. Moreover, the task of modeling what happens in the seabed sediments is far easier to do at ambient temperature than it is at the elevated temperature, so predictions of the performance of the sediments can be made with more confidence if we can contain the water with an engineered barrier during this thermal period. For periods of 600 to 1,000 years, however, we have little knowledge about how well a titanium alloy would perform. We know it survives over a short time period, but some types of corrosion have an incubation period before they start. If corrosion should begin after an incubation period as long as 200 or 300 years, it would be difficult to determine at what rate the corrosion would be likely to proceed.

Fourth, for a 10^6 year isolation period, it is obviously not worthwhile thinking about a container at all. But even in this case, if after 600 years half of our containers have failed, we have still managed to isolate half of the most dangerous waste until it has decayed to background levels without asking the ocean to assimilate it. I think that is worth doing.

In concluding then, we can say that first, the usefulness of a cannister depends on the character of the waste form. Second, for many radiological wastes, use of a canister can increase the effective assimilative capacity of the ocean. That is, by using a canister you enable yourself to put waste in the ocean without asking the sediments or the water to do the assimilating. No one, however, has yet gone through a detailed engineering design of what such a container should look like, or how much it might cost. Nor have we really addressed the relative economic and social aspects of the land and seabed options. These questions are currently being considered at Sandia laboratories, and I think that they are critical considerations.

Table 1

CORROSION BEHAVIOR AND RELATIVE COST PER YEAR OF CANISTER LIFE FOR SUGGESTED MATERIALS

Material	Corrosion Rate (MM/YR: SW 250oC)	Gamma Radiation Rate Increase	Relative Cost
Ti Code 12	0.0006	2	0.1
Commercial Purity Ti	-	-	1
Inconel 500	0.1	-	8
Lead	1.0	-	22
Hastelloy 276	0.2	-	32
90-10 Cupronickel	0.7	7	36
Copper	5.0	-	200
1018 Mild Steel	11.0	14	900

DISCUSSION

ENGLER: With regard to land disposal of radioactive wastes, high- or low-level, what is our track record? Have we contained them pretty well or not at all?

ANDERSON: For some we think that we have, and for some we have not. Some of the low-level depositories are starting to leak into the environment. Others are fine as yet.

I might take just a moment to comment on another couple of things. All of us oceanographers like to stand back and say, "Wow, we really do not know anything about our oceans," but I turn out to have one foot in each of the camps, the land-based and the ocean. And I can tell you very surely that it is all relative. We know so much more about the ocean processes than you do about the aquifers and most of the land-based stuff, that you just could not believe it. So if you want to know everything about everything, we really do not know a lot about the ocean. But if you say, "Do we know more about the ocean than we know about the equivalent land movements of, say, the water masses?" Then the answer is, by far, yes.

DEXTER: We also know more about the ocean than we know about what is going to happen to structural engineering materials in 4,000 years at 200 to 300°C.

WIEGEL: Two items of which I am aware may be of interest to you. Some time ago, I got worried about materials used in breakwaters. I found that they specified "sulfate" tests, abrasion tests, and a series of other tests which had been developed for testing the aggregate used in concrete for pavement. One report I have seen was by an engineer in the U.S. Bureau of Reclamation on his study of the condition of natural stone used on the reservoir side of earth-filled dams. He found that the "wearability" of the rock seemed to correlate only with the porosity of the rock. The lower the porosity the better the rock. Someone else studied a series of concrete clumps that had been placed in the sea by the Navy many years ago, and had recently been recovered. I believe it was found that, again, the lower the porosity the less the deterioration in seawater.

Now, there are some materials, metals that have been in the ocean for a long time. I was in the Mideast just a short time ago. One of the ancient ports that goes back to Phoenician times had a breakwater, the base of which was constructed probably about 1500 B.C. That is, it is 3,500 years old, built of huge stone with lead doweling to hold it together. So there are some metals that one could observe. I also happened to be there just after they recovered a bronze ram off a Greek ship which was probably built about 500 B.C. The point is that

there has been some experience with things, some metals, that have been in the seawater for 3,500 years, others for about 2,500. Of course, these are at the normal ambient temperatures, but it may be that we could learn a fair amount from a couple of these examples.

DEXTER: Yes, but the problem is we do not really know how to evaluate some of that because we do not really know what the starting point was. Your comments about the porosity of concrete are correct. One of the things that makes concrete last in seawater is to make it low in porosity, and that is part of the reason for the polymer impregnation. You can get nearly zero porosity, but most of those long-term things were not at high temperature, as pointed out, and so they are not directly applicable, except perhaps for low-level wastes.

HIRSCH: Have you done any preliminary risk assessment of options of high-level wastes disposal, ocean versus terrestrial and so on?

ANDERSON: The terrestrial data is just now starting to be used for risk (assessment). We have not done it on the ocean.

HIRSCH: The reason I ask is that you talked about sensitivity analysis in your model. It would seem to me that any kind of a preliminary risk assessment would suggest that the transport mechanisms would be so much risker in the ocean than they would be in a closed mine. It would seem to me intuitively logical.

ANDERSON: Intuitively, your first cut says yes. But if you look at the land transport versus the ocean transport in generics as far as risk, the ocean transport is less. If you look where all the waste is being generated at this point in time, it is on the East Coast. The first line of mine repositories being suggested are midcontinent to West Coast, which says that the most sensitive of the transport mechanisms, the land transport, you use for the longest distance. Rather than taking it 100 miles to the coast and then on board ship--

HIRSCH: I was thinking of environmental transport. In other words, if this container leaks in the ocean my assumption is it would be dispersed much more widely than if you had a similar leakage in a mine. The risk of exposure would be so much greater. This is just intuitive for high-level wastes.

ANDERSON: We have not done a detailed one. So, I cannot give you an answer, but depending on how many failed and what river system you are addressing on the land, it may not be true. If you pollute, for example, all of the Mississippi, let us just take a hypothetical situation, you have a large population to consider.

HIRSCH: My assumption would be putting this in a mine where the effect would be land contamination.

ANDERSON: But you have proximity to a river usually.

DEXTER: In the ocean the effect would be--certainly if the container is hollow and it implodes on the way down which some of the old ones did, you are going to get very rapid dispersal in the water column. But if you design the container to embed the waste in the sediment then you have geologic clay that chemically binds the waste when it leaches out of the container. You are counting on the geology itself to contain it much as you are in the mine.

ANDERSON: It turns out, also, if you look where most of the radionuclides have gone, except for the plutonium example, almost all of them end up in the sediments very rapidly. The absorption coefficient ratio, remember, is 30,000 to 1, that is, 30,000 atoms in the sediment to 1 in the water. So, what you end up doing with the debris falling down is you are literally scrubbing out the radionuclides and putting them into the sedimentary formations.

Now, whether you want to do that on a global basis or not is a question that we have not addressed.

KAMLET: Both you gentlemen indicated that where you had a radionuclide that was highly persistent in relation to the life expectancy of the container there was no point in trying to contain it, and the best thing you could do was to attempt to disperse it as finely as possible. That may be true with respect to containerization, but it may be especially important in that kind of situation to attempt to contain it geologically or some other way. I would like to note that there may be a real distinction in that sort of situation between radionuclides and other types of hazardous waste materials. You talk of persistent synthetic organic materials, for example, but the persistence of even the longest-lived of those materials does not begin to compare with the persistence of some of the persistent radionuclides. It seems to me that an important consideration, where you are dealing with persistent synthetic organics, is, to the extent that microbiological degradation and other forms of biological degradation are possible, the disposal medium which will maximize the opportunities for biological degradation. Perhaps Dr. Colwell would care to comment on this, but it seems to me that, all else being equal, if you put a persistent synthetic organic material in a land situation where you have got a fairly stable substratum for microorganisms to adapt on, that are capable of breaking stuff down, that you are likely to biodegrade the material much more readily, in general, than in an ocean environment where you do not have a stable substratum. You have less opportunity, it seems to me, for microorganisms to act on the material.

COLWELL: Unfortunately that is not the case. We have done a lot of work on deep-sea bacteria and in fact we have been able to show, along with Dr. A. A. Yayanos at Scripps, that there are bacteria --particularly in the gut of deep sea animals--that will grow only under pressure. So there are adaptive (bacterial) forms. In fact, again one of the problems with the Ocean Thermal Energy Conversion Project (OTEC) is that they did not really expect as much and as rapid biofouling as occurrs. Several years ago, when I was a graduate student, I studied bacteria isolated from Rongelap and Eniwetok Atolls. One of the real problems was that bacteria can concentrate radionucleides very nicely. So if there is any leakage or spillage of radionucleides in the deep sea, you can be sure it will get into the food chain.

KAMLET: Could I just follow that up briefly? I was not talking in terms of radionuclides in containers at present on the bottom of the ocean. I was thinking more in terms of persistence of synthetic organic materials, not nuclear material, that was dispersed in the ocean as opposed to dumped in a way that we cannot address on the ocean bottom. Does not the opportunity for biological or microbial degradation depend on maintaining contact between the material you want to degrade and the organism over a sufficient period to allow that kind of degradation to occur? And would not in a dispersal-type situation, that contact be less available?

COLWELL: Let me just say that it is well known that the fungi which are very abundant in soil can degrade many of the plastics and various synthetic polymers, and can do so reasonably readily. I say reasonably readily, i.e., within three or four months. Unfortunately deep-sea fungi and the ability of the deep-sea bacteria to degrade these materials is simply not known. So, under deep-sea conditions it simply has not been tested. I would wager, based on experience, that it would not be that different. It might be somwhat slower, but it would not be that much slower than on land, and you would have micro-organisms involved in biofouling because bacteria along with macro-organisms will attach to surfaces, even in the deep sea, resulting, eventually, in degradation. As Dr. Goldberg said earlier, we have not put our money where the important questions lie, and this is an important question to be studied.

DEXTER: If you can degrade any type of waste within the reasonably expected lifetime of a container in a given environment, then it is worth thinking about the container. I agree with you.

CURTIS: Dr. Anderson and you were describing the models that you look forward to having in place sometime in 1983, describing the biology, the sediments, and water models.

One thing that concerns me, to the extent that I follow the seabed disposal program, is the correlation with monitoring of past dumping that is primarily being done under EPA auspices with some

assistance from the National Oceanic and Atmospheric Administration. It now appears that in fiscal year 1982 that will be zero budgeted. There is not going to be any further monitoring of the offshore dumping that was done in the fifties and sixties, and the only opportunity, I guess, to look at canisters which are down there in the deep ocean will be the extent to which we will participate in the international review of the Northeast Atlantic dump site.

To what extent do you foresee that your program might turn to that laboratory of opportunity to help further develop a model approach? The second speaker (Dexter) expressed a feeling that we are talking about a different generation of canisters, but still there is something to be learned from there in terms of the sediment, the pathway to man. It seems that we have done too little, and our sampling has led to the conclusion, such as at the Farrollon Islands where it was said that there is no harm, that we still need to know more. There is that opportunity from the canisters that are out there in great numbers in places like the Farrollon Islands, Massachusetts Bay, and other areas of our coastline. Could you comment on that aspect?

ANDERSON: I agree with you that we in the United States probably will not do any more about the low-level dump site monitoring.

In order to get answers that are usable from either of our dump sites we must be very careful on the research that we plan. Most of the research to date has been very interesting but absolutely useless in a predictive model--just the same as the biology discussions that we had earlier. For example, because radionuclides in a canister very quickly become attached to the sediments, you need to have a very good spatial sampling close to a barrel, a spatial sampling where you have not perturbed the bottom and laid a layer of sediment on it. It was not done. There is not enough data, was not enough care taken to get samples that are usable to check my models; all we have is Vaugh Bowen's work, the tritium work that was mentioned earlier, from bomb fallout, and some freon work that is starting to be really good that we can use as tracer systems from the ocean dynamics. But at this point in time I would be very careful before I would suggest any additional research.

DEXTER: It is very difficult to do that pinpoint sampling. I think we have the technology to do it now. If we can reenter a drilled hole, we certainly could do that, but it would be very expensive, and it is by no means a trivial matter.

GAITHER: Thank you, gentlemen. I think we are probably going to have to stop here and let the questions that are obviously very interesting continue later in an informal setting. I hope those interested in this will do so.

MARINE POLLUTION MONITORING
AND ASSIMILATIVE CAPACITY

by

R. L. Swanson* and G. Peter

Abstract

The assimilative capacity concept in marine waste disposal implies that most bodies of ocean water can physically disperse, chemically, dilute or neutralize, and biologically breakdown or digest certain amounts of added materials to a degree that those concentrations that remain will not produce unacceptable impacts on the ecosystem or on the human population through contact with that system. If one can establish the major pollutants of concern in a given marine environment, the major resources that are threatened by these pollutants, and the degree of permissible impact on these resources, then a rather inexpensive monitoring program can be established to assist waste management and resource protection. The assimilative capacity concept hypothesizes that we know enough about ecosystem functions that we can quantify the loadings of certain pollutants in the seawater in terms of their impacts on environmental targets. We propose a gradual implementation of this concept with a corollary monitoring program to test the hypothesis. The monitoring required can be accomplished as part of a national marine pollution monitoring strategy. The strategy links existing compliance monitoring and trend-assessment monitoring programs into a regional and national framework, and proposes the rationalization of monitoring program objectives on the bases of assimilative capacity criteria and management information needs, and the rationalization of station selection, based on a hierarchical approach.

Introduction

Conflicts will increase in the coming decade between the need to protect and the need to use and develop our coastal marine resources. Urban and industrial growth, changing energy uses and requirements, and the cost and lack of acceptable alternative waste disposal options will require an increasing and more diverse intrusion into the marine

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environment.* The pressure is already increasing on legislators to reconsider whether the environmental goals of the late 1960s and early 1970s were too costly to achieve, and whether the right balance between environmental quality preservation and marine use was made. Congress passed the National Ocean Pollution Planning Act of 1978 (P.L. 95-273) to require the federal agencies to better plan and coordinate their activities toward a rational, efficient, and equitable utilization, conservation, and development of our ocean and coastal resources. The National Advisory Committee on Oceans and Atmosphere (NACOA) was also critical of our national policies and regulations concerning the nation's waste management strategy, in general, and waste disposal in the ocean, in particular.[1] The committee's report stated that the medium-by-medium approach toward the management of society's waste material has led to conflicting goals and objectives. They recommended an integrated approach that considers the impact of one medium's regulation on other media, and stated that wastes should be disposed of in the manner and in the medium that minimizes risks to human health and the environment, and at a price that this nation is prepared to pay. NACOA stated that there is a high probability that land, deep-well, and atmospheric waste disposal activities will be reduced in the 1980s in favor of disposal in the oceans which, in the committee's point of view, is a reasonable option to consider.

If ocean disposal of wastes becomes a more widely accepted practice, it will be even more urgent to understand the consequences and the effects of the possible range of waste management decisions. The types of pollutants and their input rates will have to be controlled, based on their combined effect on the ecosystems of the receiving waters. Effects of pollutant loads will be different in differing ecological and physical environments based on the assimilative capacity criteria of the given ecosystem. Monitoring should be undertaken to test the standards established for pollutant impacts and for the assimilative capacity criteria of pollutants in a given ecosystem, and to assist a variety of other management decisions for environmental protection and pollution control.

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*An April, 1981, decision in New York Federal District Court maintained in The City of New York vs. The United States Environmental Protection Agency that EPA failed to prove that New York City had fouled the sediments in the water column of that dump site. Judge Sofaer required the data to prove that a particular dump is responsible for pollution. A number of municipalities use the site in question.

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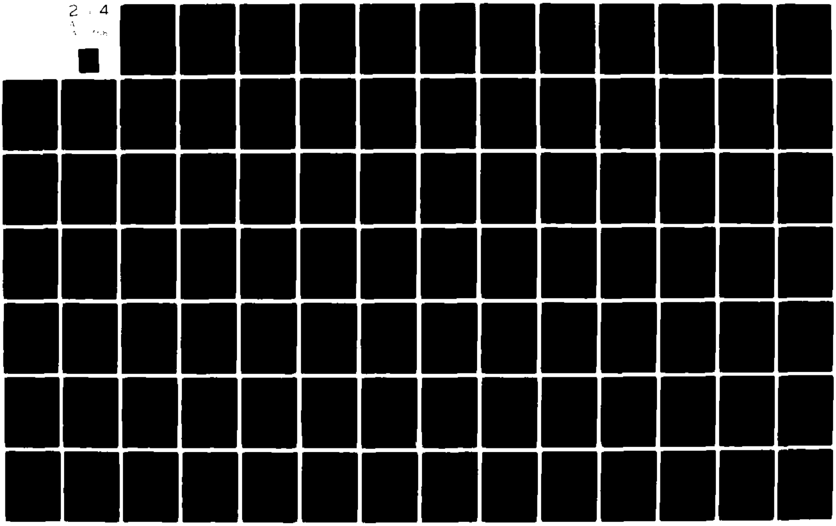

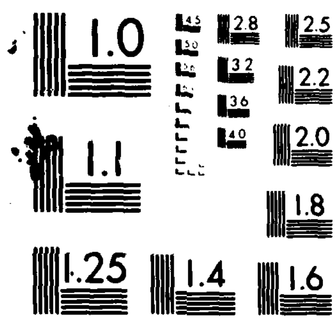

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Assimilative Capacity

Assimilative capacity of a given body of seawater for a given pollutant can be defined as the maximum amount of that pollutant that can be contained within that volume, without producing unacceptable impacts on the ecosystem or on the human population through contact with that system.

This definition, a slightly modified version of Goldberg's,[2,3] deals only with the general concept of assimilative capacity and assumes that the physical, chemical, and biological processes leading to "assimilation" can be established. In detail, application of the assimilative capacity concept requires complex policy and management decisions (multimedia disposal considerations, socio-economic consequences, value judgments on resources and ocean uses, etc.) and considerable scientific understanding of the involved ecosystems and of the limitations of the assimilative capacity concept. One has to identify: (1) the critical biological and physical components of the ecosystem (end-points or indicators) upon which assimilative capacity will be established and monitored; (2) the "given water body" within which uniform conditions may be assumed; (3) the critical pollutant types, input locations, and volumes and rates of release; (4) pathways, transformations, sinks, and flushing rates; (5) synergistic, antagonistic, and chronic low-level, long-term effects; (6) the criteria for "unacceptable impacts"; and (7) the verification procedures.

Assimilative capacity of the ocean is a concept that society needs to deal responsibly with the existing and projected uses of the ocean in the coming decades. The Global 2,000 Report to the President clearly suggests that our ocean-use management policies must reflect not only the present, but also the expected national priorities.[4]

It is clear that there are some highly persistent and toxic materials (radioactive wastes, PCB's, etc.), to which the assimilative capacity of a highly valued ecosystem may be defined as zero. Also, there are numerous valuable coastal ecoystems (critical habitats, sanctuaries, fishing grounds, etc.) upon which no pollution impact whatsoever will be desired, and which, therefore, will require the same assimilative capacity designation: zero to all pollutants. On the other hand, there may be selected water bodies (estuaries, bays, enclosed deeps, etc.) that already have received so much pollution, or have been designed as pollutant containment sites, that their value beyond navigation and waste containment is minimal. Given the importance of the local economy involved and/or the forbidding social costs necessary for mitigation, these areas may be designated to be used further as disposal sites, with their assimilative capacity designation reflecting this status.

The assimilative capacity concept, together with multimedia disposal considerations represent a rational management option for marine waste disposal. The need for adequate scientific knowledge indicated by Goldberg[3] and emphasized by Kamlet[5] are acknowledged; however, it is necessary to begin implementation of this management concept if we want to avoid economic and social hardships and legal confrontations which could cause delay for years and to attempt to protect and develop our coastal oceans in a rational, cost-effective manner.

To develop fully the application of the assimilative capacity concept in waste management, a long-term committment will be necessary to develop further the scientific data base, to test the hypotheses, and to define rational assimilative capacity and other pollution criteria. To accomplish this, there is a need to coordinate in each coastal regions the existing federal, state, local, municipal, and industrial marine pollution programs, whether these are regulatory, management, or monitoring. Also, there is a need to develop an optimal regional marine pollution managment and monitoring network, based on a clear set of objectives and decision framework, and on the rational afforded by the assimilative capacity concept. In the following, we shall discuss a proposed national monitoring framework, and the role of assimilative capacity within that framework.

Monitoring

Rationale of Programs and Their Inadequacies

Monitoring should become an important tool of marine pollution management. Its role could be twofold: on one hand, it could serve to warn against the unacceptable impacts of human activities and waste products on the physical and living marine environment (mankind included) and, on the other, it could provide a long-term data base to evaluate and forecast natural changes and the impacts of human activities.

In the Federal Plan for Ocean Pollution Research, Development, and Monitoring, Fiscal Years 1979-83, monitoring was defined as systematic, time-series observations of predetermined pollutants or pertinent components of the marine ecosystem over a length of time sufficient to determine: (1) existing level, (2) trend, and (3) natural variation of parameters in the water column, sediments, or biota.

Monitoring programs can be classified in many different ways based on program objectives, function, monitoring parameters, polluting activity, and so on. By using a functional criteria, four monitoring activities may be distinguished:

1. Compliance--monitoring conducted for the purpose of establishing whether or not a pollutant source is meeting the requirements of a permit or regulation;
2. Environmental--monitoring of environmental variables which lead to assessment of pollution conditions and pathways (e.g., beach-water quality and pollution pathways to edible fishes);
3. Ecological effects--monitoring of biological responses from the individual to the ecosystem (including people) to detect ecological consequences of pollutant stress; and
4. Health effects--monitoring of pathogenic or indicator microorganisms in water and shellfish, and toxic materials in fish and shellfish for the purpose of determining impact on human health.

In this paper we further simplify this categorization by adding the elements of health effects monitoring to compliance monitoring and by incorporating the ecological effects and environmental monitoring under the title "trend-assessment monitoring." In the latter category (see Table 1), we highlighted the variations of pollutants and pathogens in the environment, which is implicit in the environmental monitoring definition.

Existing marine pollution monitoring activities are conducted in response to several specific legislative mandates. Without providing a

Table 1

Compliance/Trend-Assessment Monitoring

I Compliance Monitoring	- municipal and industrial effluent - ocean-dumped substances - toxics and pathogens in: a. biological organisms b. physical environment
II Trend-Assessment Monitoring	- concentration variations of toxics and pathogens in: a. biological organisms b. physical environment - ecological variations - environmental variations

comprehensive summary, the major ones are: The National Environmental Policy Act of 1969 (P.L. 91-180), The Federal Water Pollution Control Act of 1972 (P.L. 92-500), The Marine Protection Research and Sanctuaries Act of 1972 (P.L. 92-532), and the Clean Water Act of 1977 (P.L. 95-217). In addition, there are several applicable fisheries and wildlife protection and management acts, and legislation involving

coastal waterways and the development of the coastal zone. A given law usually requires coordinated action from several federal agencies. In addition, through the regulatory process and interactions, the effects of legislation extend to many agencies at the state and local levels, and these, as well as organizations such as industrial and municipal dischargers, are required to undertake a variety of marine pollution monitoring activities.

Based on the diverse responsibilities of the various organizations and agencies, and on the large number of individual program objectives, the present array of monitoring programs is very complex. The majority of the approximately 1,000 existing programs are conducted in response to regulations, which require that those who must discharge wastes into the marine ecosystem must assure that no harm is caused by their activity. The federal roles should be to assure that: (1) appropriate safeguards (regulations and management schemes) are in effect, and (2) efforts are continuously made to synthesize monitoring information, and to increase the utility and cost-effectiveness of the programs. The fact that improvements are needed in both areas have been established by recent NOAA and EPA workshops on marine pollution monitoring.[6] Needs to improve cooperation and communications among the various organizations involved in monitoring, to define clear objectives for individual, regional, and national programs, to regionally plan and coordinate monitoring programs, and to provide better accessibility and dissemination of data and information in a given geographic region have all been documented. In order to implement effectively these and other recommendations of the workshops, it is necessary to define in each geographic region rational monitoring objectives and an optimal regional marine pollution monitoring scheme which, when combined from all regions, will become a national marine pollution monitoring program. To proceed, however, it is necessary first to develop a general framework for a national program, and to provide guidance for the establishment of rational objectives. We propose the use of waste management needs and the assimilative capacity concept for the definition of rational objectives for the monitoring programs, and a hierarchical scheme to be established on the basis of existing and anticipated impacts for the rationalization of sampling requirements.

Previous suggestions for the establishment of a marine pollution monitoring program on a national basis, and the difficulties of implementation and support of such a program have been documented by Swanson and O'Connor.[7] They listed as the major problems: (a) the division of responsibilities among a large number of organizations with diverse objectives, (b) the cost of monitoring, and (c) the scientific and technological limitations. In addition, one may list the lack of clear mandates for a national program, the lack of defensible objectives and benefits, and the lack of an organizational framework and relationship between the proposed national program and the other existing programs for the absence of support. We believe

that the mandates of the National Ocean Pollution Planning Act of 1978 (P.L. 95-273) requiring joint planning and coordination of federal marine pollution programs, changing attitudes in legislatures, and the mounting pressures to establish a rational waste management strategy provide now a favorable climate for a well-designed cost-effective national marine pollution monitoring program.

Proposed National Marine Pollution Monitoring Program

The following are the principles behind the national program we are proposing: (1) Monitoring should be utilized as a major marine waste disposal management tool; and (2) the national program should be, basically, an integrated program of data and information management and quality assurance, relying almost entirely on existing monitoring programs for data. It is not proposed to establish a major independent program in addition to the existing programs, as was suggested in the past.

Users of the national marine pollution monitoring program will be the agencies that have the authority to control the input of objectionable materials to the marine environment, the public and private institutions which will be affected by the controls, and federal, state, and local government bodies that are concerned with the management of our coastal resources.

The goal of the national marine pollution monitoring program should be to assess the state of pollution of the coastal ocean (estuaries and the Great Lakes included). The two objectives proposed for the national program are based on the dual roles of monitoring: (1) provide warning against imminent harmful impacts; and (2) provide evaluation and forecast of long-term impacts.

The first objective should be accommodated by the existing compliance monitoring programs. Compliance monitoring programs are performed to meet the requirements of permits or regulations, and to provide assurances that predetermined water quality and health standards (including fish and shellfish safety standards) and effluent criteria are not violated. Compliance monitoring, in a sense, satisfies the immediate legal-political requirements.

The second objective should be accomplished by the trend-assessment monitoring programs, which are conducted to assess the ambient conditions of coastal marine ecosystems, and to predict and hindcast, insofar as possible, responses of the ecosystems to natural changes and human influences, whether these are in the nature of crisis events or long-term, chronic problems. These trend-assessment monitoring programs are not required for legal compliance, but are essential to provide a long-term data base for a scientific-environmental understanding.

To meet these objectives efficiently, effectively, and economically will be a considerable challenge. They call for a program of national scope with regional ecosystem emphases and specified uses. They also call for sufficient understanding of ecosystem responses which can be related to stimuli. In establishing a framework, management should be emphasized instead of data collection. Efficiency is to be gained through careful selection of useful measurements, intercalibration, quality assurance and analysis--avoiding excessive data collection.

The components, or program areas of the national monitoring program (Table 1), will have to be established and tailored to the individual needs of each region. Depending on regionally defined management needs, emphases on the different components of the program, therefore, will be different in each region, and several components in a given region may even be omitted.

Discussion of Program Components

It is expected that during the first years of the development of the proposed national program, compliance monitoring activities will need to continue unchanged. Additional benefits to these programs will occur with time, as the trend-assessment monitoring programs improve our understanding of the marine ecosystems and thus allow for the reduction of the complexity and costs of the present programs. Eventually, the implementation of the proposed national program should lead to a reduction of compliance monitoring requirements to reliable input characterization and to occasional spot-checks of near-field environmental effects in the immediate impact zones. However, effective regional management could identify participants with similar data requirements, and by cooperatively sampling and sharing data, in some cases immediate savings could result to participating programs.

In the area of the trend-assessment monitoring programs, the assessments of pollutant concentration trends initially also have to rely on data available through compliance monitoring. However, the aim of this part of the program is to obtain an overview on a regional and national scale, and for this purpose we propose program augmentation. At present the most promising, cost-effective approach to such a broad overview is the use of sentinel organisms.[2, 8] Such a technique needs to be employed when it is suitably perfected. In addition, a few carefully selected base stations need to be established in each region in impacted, potentially impacted, and pristine areas to provide another, somewhat independent, assessment of the regional conditions. Broad-scan chemical analyses should be performed on the sediment and biological samples that should be collected at these stations at predetermined intervals, but certainly no more than annually. The stations should be selected and sampled in such a manner that assessment of the changes of the severity of the impact, and

variations of the pristine area conditions are established. Because of the high costs of analyses involved in this part of the program, regional planning, coordination, and selection of priorities will be critical.

The ecological and environmental variations parts of trend-assessment monitoring tie the short-term near-field data of compliance monitoring to long-term, regional variations. The objective is to identify major, significant regional changes, and to establish whether these were caused by natural variability, or were human-induced.

A large part of ecological variations monitoring could be satisfied by existing survey programs, such as fisheries and shellfish assessments, catch statistics, habitat investigations, and so on. Existing programs from federal, state, academic, and private organizations should be identified and their data should be analyzed and incorporated into the regional monitoring data bases. Data gaps should be identified and brought to the attention of appropriate agencies for action.

In the area of environmental monitoring, a similar search for existing programs and data are recommended. However, existing programs may have to be modified and, where needed, new regional programs will have to be initiated to determine major changes in ocean climatology. This will tie major water-mass changes to the physical and chemical control of primary production which, in turn, affects the upper levels of the food web. The objective is to establish the natural oceanographic variations and their ecological consequences, a knowledge that is necessary if the human impacts on marine ecology are to be understood.

Advantages of the Proposed Program

To establish a national marine pollution monitoring program based on the idea to measure every possible pollutant everywhere in the ocean with the utmost scientific precision and statistical and legal validity, and to be able to anticipate and respond to all possible contingencies--often in a very short time frame--, may be a desirable scientific approach but, today, it is an indefensible management goal that is, simply, beyond what this nation is willing to pay for. The framework we propose (Figure 1) is designed to serve the actual management needs of local, state, and federal agencies and the other participating organizations; program objectives are focused further by looking for the combined effect of key pollutants on ecosystem targets and by using the assimilative capacity concept. The monitoring efforts under consideration should be able to relate pollution sources to their

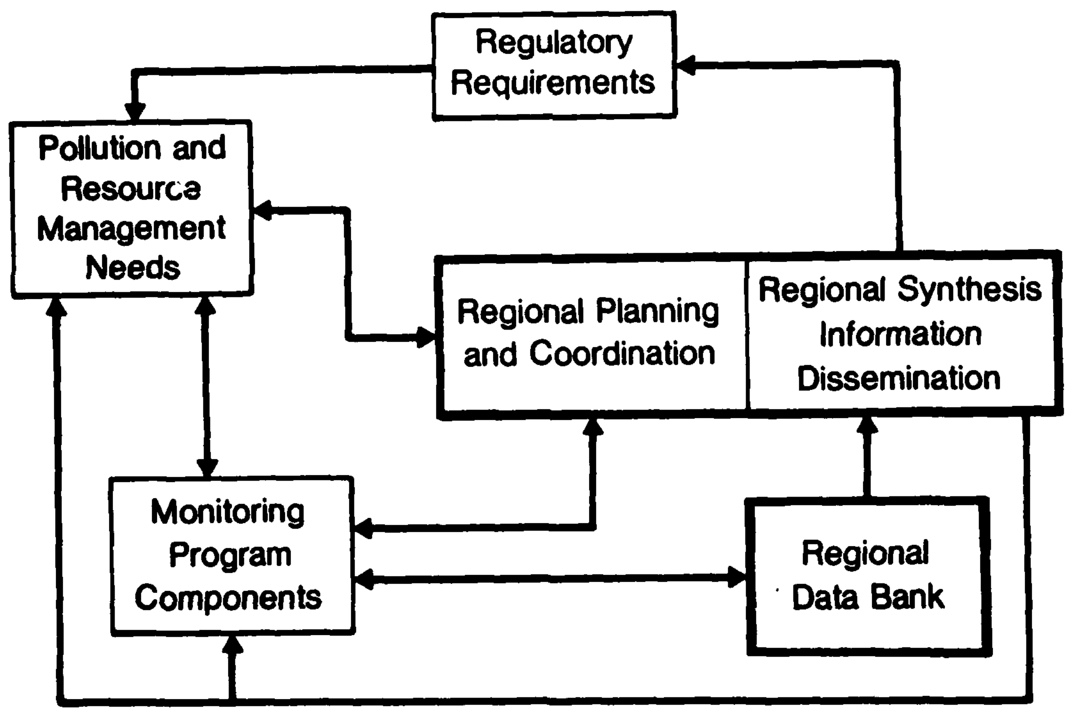

Figure 1. Regional Monitoring Framework (accented boxes represent the proposed new additions.

environmental effects, and thus they should allow the implementation of a rational waste management strategy that is based on the characteristics and assimilative capacities of the regional ecosystems.

The national marine pollution monitoring program is designed to work together with our current and anticipated system of environmental laws and regulations (to be modified on the basis of the results of this monitoring program) that are expected to (1) effectively control the inputs of highly toxic pollutants to the oceans; (2) reduce the potential for surprise pollutants; and (3) lead to a much better knowledge of the inputs that do remain. The proposed national program therefore, has limited, rational objectives, based on regionally developed definitive priorities and, consequently, will be cost-effective.

Because the proposed national program is built up from regional management requirements, and because, basically, it is coordinated information and data management of existing programs, the national marine pollution monitoring program will become an integral part of the marine pollution management process, supplying information to such diverse needs as marine waste disposal options, pollution control strategies, determination of guidelines, evaluation of standards, resource development and protection, and needed changes in legislation. In essence, the framework will unify the program components under a regional management/decision-making umbrella, and will establish in each region an authoritative source for information.

Another advantage of the proposed national program framework is that it can be implemented without adverse effects on existing programs. Joint data usage and access to a much broader data base will result, in cases, in immediate savings, and more informed decisions. In addition, the national marine pollution monitoring program will have information useful to other areas of ocean management than marine pollution--such as, fisheries management, marine transportation and recreation, energy production and planning, and so on.

Another benefit of the proposed national program approach is that a regional and national management framework could greatly facilitate testing and adoption of quality control programs, technology intercomparisons and intercalibrations, and standardization of certain methodologies.

Last, by driving the national program from the point of view of management needs, the proposed framework provides total flexibility. Supporting research and technology development can follow a parallel, but independent course. Cost effectiveness, and management needs and benefits will control the evolutionary changes of the regional

monitoring networks which will need to be modified, based on our improved understanding of the ecosystems, pollution effects, assimilative capacities, and available and affordable new technologies.

Program Implementation

Cost effectiveness of the national marine pollution program has been discussed already from the point of view of limiting or rationalizing objectives. Additional savings can be achieved by similar rationalization of the geographic coverage. We propose that the national marine pollution monitoring program be hierarchical, similar in organization to the national geodetic network. In the geodetic network there is a basic, widely spaced station-net reference system to establish a national standard. Several more dense networks tie into this national standard net, each having been established on the basis of regional or local survey needs. To apply this principle to the national marine pollution monitoring program, the station-net for sentinel organisms can be considered as the program's basic net. By using this perspective, the other monitoring programs should be established only on the basis of actual needs in geographic areas that may be defined as "control areas." Monitoring the control areas corresponds to the activities of the local surveyor in that the monitoring activities are designed to meet local needs.

The first steps to begin implementation of the national marine pollution monitoring program should be to: (1) determine appropriate geographic areas as regions; (2) identify in each region the monitoring requirements, and the major organizations and their appropriate monitoring programs for inclusion; and (3) identify the organization that would serve as a focal point in each region. In keeping with its responsibilities under the National Ocean Pollution Planning Act of 1978, NOAA will continue to coordinate the activities necessary for program implementation. It will be necessary to organize regional task groups, composed of the representatives of regional monitoring organizations, to deal with the major issues of organization, data access, and information dissemination, and to develop regional monitoring plans with all the program components, objectives, and interactions identified. The regional management and decision framework and the detailed assessment of the resources that will contribute to the program will have to be carefully documented. It must be reemphasized that the regional management is for the purposes of coordination and information assessment, synthesis, and dissemination. None of the proposed activities are to interfere with or to weaken the well-established state and local responsibilities and programs.

Monitoring and Assimilative Capacity

The adoption of the assimilative capacity concept in marine waste disposal implies the recognition that most bodies of ocean water can physically disperse, chemically dilute or neutralize, and biologically break-down or digest certain amounts of added materials to a degree that those concentrations that do remain will not be beyond the limit specified as acceptable. Although quality criteria of receiving waters are reflected in our water pollution control laws, the emphasis of past legislation has been on effluent standards and control technology.[9] Municipal and industrial dischargers also criticized regulations that require that technologically based standards be applied uniformly to all facilities nationwide.[6] They argue that treatment and disposal criteria of waste waters and other discharges should be regulated on the basis of the conditions of the individual receiving waters. A change in pollution control philosophy toward this direction is reflected in the 1977 amendments of the Federal Water Pollution Control Act, where Section 301(h) of the amended law provides for granting of waivers of the secondary treatment requirements on a case-by-case basis. This waiver recognizes the varying capacity of the local waters to accommodate wastes. But, in order to assure that conditions in the receiving waters are maintained as they were identified in the 301(h) waiver application, the dischargers are mandated to implement a monitoring program.

Not only the assimilative capacity of different water bodies are different, but within a given water body the assimilative capacity may vary from season to season, year to year, or from decade to decade. Monitoring is necessary to detect changes due to natural variability and to the changing anthropogenic input, and to alert management for remedial actions if necessary.

Monitoring for assimilative capacity criteria, therefore, is covered by the roles of monitoring and the types of programs we have identified previously. Management decisions, based on monitoring data, could include:

1. change treatment procedures (remove components, change concentration, require higher level of purification),
2. change rate of discharge,
3. change amounts of discharge,
4. change location of discharge,
5. suspend discharge,
6. restrict usage of the polluted resource,
7. change water quality and/or assimilative capacity criteria, and
8. recommend new or modified legislation.

Present standards and treatment procedures of effluents could be modified on the basis of assimilative capacity monitoring data, and these procedures could be adjusted further on the basis of the natural

variability of the assimilative capacity of the ecosystem components. The management organization of the regional monitoring networks has to establish effective communications among the regulatory government bodies and the dischargers, so that adequate time is available for discussions and actions on the options available.

In essence, the assimilative capacity concept should serve as one of the major guides for the rationalization of the objectives of monitoring programs. Regional plans should identify the major polluting activities, the key pollutants of concern, the threatened resources, and the endpoint or target components of the ecosystem that need to be monitored. Assimilative capacity standards should be established on these targets on the basis of existing knowledge from laboratory studies and understandings of the ecosystem. These and the entire program should be flexible and should be fine-tuned on the basis of new management needs and new monitoring data provided by programs such as the regional wide-scan for pollutants, determinations of the size and locations of impacted areas, resource assessment surveys, and ocean climatology.

Summary

The new, integrated approach toward the solution of society's waste disposal problems on land, in the sea, and in the air, and the present economic constraints will exert increasing pressures to turn more frequently to the marine waste disposal option. In light of this trend, there is a need for more effective interaction among the agencies that are involved in the control and management of marine waste disposal and resource protection. We propose that the establishment of a national marine pollution monitoring program could facilitate the needed management interaction and would provide the data base necessary for rational waste management and resource protection decisions.

The objectives of the national marine pollution monitoring program would be: (1) to provide warning against imminent harmful impact, and (2) to provide evaluation and forecast of long-term impacts. As opposed to the establishment of a major, new data collection program, the suggested national program would rely mostly on the existing compliance and trend-assessment monitoring activities. The national marine pollution monitoring program would be the sum or a mosaic of regionally designed monitoring networks, consisting, in essence, of regionally integrated data and information management. New program augmentations would be kept to a minimum.

Major criteria in the design of the proposed program are: to serve management information requirements, and to be cost-effective. Regional management teams are expected to assess information requirements; cost effectiveness is to be achieved through rationalization of monitoring program objectives and sampling designs.

The adoption of the assimilative capacity concept can serve to guide rationalization of monitoring program objectives. In each geographic region, management will have to identify the key pollutants of concern, the major resources of concern, the targets or indicators of stress of the resources, the limit of impact allowed on these resources, and the management decision options based on the monitoring information. Additional monitoring will be required to satisfy short-term management needs, and to obtain data on pollutant inputs, and variations in pollutant concentrations, ecology, and ocean climatology. These monitoring efforts will require long-term commitment if we are to be able to distinguish between natural and man-induced variations in the quality of our coastal resources.

Rationalization of sampling design requires that both the areal coverage and the sampling frequency be carefully scrutinized. The approach suggested is hierarchical similar on organization to the national geodetic network. To provide a broad regional or national overview, a wide network of stations should provide information on the range of critical pollutant concentrations. Further evaluation and eventual implementation of a sentinel organisms type approach is suggested for this purpose. More detailed monitoring activities should be restricted only to "control areas," which should be defined on the basis of actual pollution threat or other concerns identified by the regional management team.

Recommendations

We offer here some broad suggestions which address not only monitoring and assimilative capacity, but also waste management in general. There are clearly some components of waste that are reaching the marine system which should not. Toxic organics, as a general class, are examples. Greater emphasis on early identification of unacceptable pollutants in the marine environment is needed. Industry must assume more responsibility here. Once these materials are identified, effective means of source control or pretreatment should be implemented.

Engineers should be looking at more effective ways to inject or place waste materials into the marine environment. While outfall design has become extremely sophisticated, ship and barge disposal techniques could be examined for the purposes of increasing dispersion, in some cases, or of assuring concentration in others. For example, there are times when dumping below pycnocline are advantageous to that of discharging at the sea surface.

Capping of contaminated dredge spoil is to be explored. This same technique has been suggested for covering of PCB-contaminated sediments in the Hudson. Isolation and containment procedures are worth more investigation.

Finally, we must come to grips with the fact that the implications of present bioassay techniques for contaminant effects in nature require many tenuous assumptions. These tests measure the short-term effects, on a few organisms at best, of contaminated wastes in very artificial situations. Bioassays also ignore the total load of the material going into the environment and the cumulative effects of all other materials as well. Techniques must be developed for more properly assessing and monitoring the effects of diverse and continuous loadings. These are the keys to developing realistic endpoints and thus waste management through the assimilative capacity concept.

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DISCUSSION

HIRSCH: I think there is something a little bit wrong with the term "assimilative capacity" that is being used here and maybe, also, in Dr. Goldberg's presentation. I think it could lead to a little bit of confusion as to how this thing is approached. You say that assimilative capacity is the amount of pollution which does not produce unacceptable impacts. It seems to me that in any kind of environmental impact assessment, in general, we try to do three things. We try to either predict, or forecast, or measure something happening. The second thing that we try to do is determine the significance of that something, and the third thing we try to do, which is a social, economic, and political judgment, is the acceptability. But there is a big difference between determining significance and determining acceptability, and what may be acceptable at any given time socially, politically, economically may exceed the assimilative capacity.

The assimilative capacity, I would think, is generally defined in terms of an environment receiving a waste in some way that either does not exceed the resiliency capability or some other ecologically defined terminology, but the term "acceptability" does not have anything to do with that. For example, we may put a waste in and wipe out an oyster bed. That could be totally acceptable in terms of political and economic trade-offs, but it certainly could not be said not to be exceeding the assimilative effects. So, I think, at least in my connotation of the terminology there is a confusion.

GOLDBERG: Let me take your oyster bed example. My sense is, if you wipe out the oyster bed and it is acceptable to society, it does not exceed the assimilative capacity if it does not bother economically, socially, or scientifically. There is no problem at all.

HIRSCH: That definition of assimilative will vary over time or--

GOLDBERG: Absolutely.

HIRSCH: So that the assimilative capacity of a river flowing between two states would be defined entirely differently according to the political and economic determinations.

SWANSON: I think, however, that you can attach caveats or whatever you want to make the definition as rigid or flexible as needs be, and perhaps we should attempt to do that.

I just took the definition that essentially came out of the Crystal Mountain meeting.

HIRSCH: It has been used a lot in sanitary engineering over the years in freshwater systems I know and generally it has been used to define the point at which the waste degradation does not so change the functioning of the system that it becomes anaerobic or goes below a certain oxygen level or whatever. It has not been used in terms of setting a standard as to what you want to use a river for. In other words, you can use a river as an industrial sink and not be said to maintain the assimilative capacity.

SWANSON: I understand what you are saying. I think when we were discussing it, though, we recognized that there were social values and economic values that somehow have got to be taken care of, and in this case, they were included in the definition.

BROOKS: I think, Dr. Hirsch, that your point is that we are really trying to separate out the science and engineering and economics rather than get them all in the pot right at the beginning. It seems to me that there is a very important question of input and response, and these are scientific questions, even significant with what it does to the ecosystem. Then, it seems to me, if you use this assimilative capacity concept you are confusing the social judgment with the basic measuring program right at the very front end.

HIRSCH: That is my basic concern.

UNIDENTIFIED SPEAKER: We talked about this at Crystal Mountain. I think the importance was the feedback. To identify the end point requires some sort of social input, and you have to realize, at some point, that science will tell you what the options and alternatives are, and social values will then have to take over. It is important to have that feedback and recognize that it is an important problem, plus a value judgment.

WIEGEL: I have been reading reports here and there. I want to ask whether or not anyone is making these studies because I remember some years ago--and Norm Brooks may remember--when the sanitary engineering and the public health people were interested in comparing data. Of course everything built up from kids swimming in lakes and rivers, but they forgot that kids did not swallow salt water more than once. Furthermore we have almost no enteric diseases. So they thought maybe the thing to do is go down to Rio de Janeiro and study it where you have raw sewage dumped out and high levels of enteric disease. Do not study it in the United States. Go down to where you have it, and then you can perform tests. Recently, I read an article about the East Pacific and all sorts of chemicals. Are we studying the biological activity, the mellifluous brines in the Red Sea which were very hot. Are we studying those from a biological standpoint? This formation of this island off of Iceland, shows tremendous underwater volcanic eruptions, with all sorts of minerals and so forth and heat being put in. Are we taking advantage of some of these great things

where the level of what is happening might be so high that we could really measure something, or at least measure it easier? I am asking. I have no idea whether or not these natural events are being used to look at this.

SWANSON: I think, in fact, they are at some level, and I know that in the federal budget process there is a considerable effort to do exactly that in years to come.

WIEGEL: We should not lose sight of these things.

SWANSON: That is correct. The Gorda Ridge is one that is being considered very closely.

COLWELL: In fact, some fascinating work is being done on Mt. St. Helens showing growth of bacteria in lakes where the temperature is practically boiling, as well as enormous amounts of heavy metals. John Baross has observed fascinating bacteria to be present in these waters. They are already recolonizing the lakes, as well as algae.

CSANADY: One comment about monitoring in general. You (Swanson) mentioned that the court did not believe that the effects could be tied to New York City's actions in the case of New York Bight. In the case of this situation where you have relatively clear-cut sources and effects and a lot of investigation, do you think that it is any better at the present time to do more extensive monitoring anywhere else around the country? Is it worth spending any money on monitoring at this point, when we really do not know what to monitor, until we understand a great deal more about these processes that control the levels and whatever is acceptable or unacceptable, until we can understand what kind of processes are taking place. I do not think we can effectively monitor. It will remain some kind of devious operation as long as the understanding is inadequate.

SWANSON: I have to agree with you. However, I think there are some clear-cut cases where monitoring can be effective and should be done. In the case of New York it was an unfortunate situation that you are dealing with many, many sources of material, and when they ask you to sort out the sludge problem, you are working with 10 percent of the issue. So you are spending most of your time looking for the signal in a huge amount of noise. There are cases, though, where resources are at risk and you can specify that there should be some monitoring effort. I certainly think, from just the national point of view, that the sentinel organisms approach is most important, that we go ahead with and try to implement. I think there is a lot of good information in that.

SEGAR: I think I would like to clarify what Judge Sofaer said. You have characterized his entire ruling in just one piece of what he said. I think he did say that there was not sufficient evidence to

establish a cause and effect relationship between sludge dumping and any impact on dump site. But even had that relationship been established, he said that EPA, in fact, had violated that act in not establishing that those impacts were, in effect, of more serious consequence under the definition of unreasonable degradation than the impacts of the alternative land disposal.

SWANSON: I agree with you, but that is really not the issue in this discussion.

SEGAR: But I think the implication was, from what you said, that if you would simply establish cause and effect relationships then legally you would have come out the other way.

GOLDBERG: I want to point out that we have utilized the concept of assimilative capacity over the last 30 years very effectively. My example is the management of radioactivity in the environment by the AEC (Atomic Energy Commission) which began in 1953 when a group of scientists recognized that we could jeopardize human health by promiscuous release of radioactive substances into the environment. Questions were asked about the assimilative capacity of the atmosphere, of the oceans, of land for wastes. As a consequence in the U.S., the U.K. and Russia, criteria were developed to manage the release of these materials to the environment and very effectively. Today I think we have looked back upon this work with great pride.

What has happened since then? We have had great concerns about a large number of other pollutants, heavy metals, and the synthetic organics. We have had a lot of government agencies grown up, and contact with the scientific community has been lost to a large extent. We see more of the legal questions. We hear institutional questions. The scientific questions often are dropped out. I can give you many examples of terribly important scientific work that seeks and cannot find the support from mission-oriented agencies because these agencies simply cannot comprehend the importance of the problems.

I should not institutionalize. My sense is that we should deinstitutionalize environmental problems and seek out a laboratory such as NCAR, (National Center for Atmospheric Research) which is dedicated solely to institutionalize problems not supported by any agencies. I think if we could develop such a laboratory to seek out answers to these terribly important questions we are posing today, we could get further ahead in maintaining environmental quality.

HIRSCH: My response to that is only that you would stand a better chance of seeking out answers when you separate out the scientific component of this from the social and regulatory and political

determinants. My concern about the definition of assimilative capacity here is that it tended to cluster these, in a confusing way, with that use of the word "unacceptable."

GAITHER: On that note of harmony, we should conclude this afternoon.

SCIENCE AND TECHNOLOGY NEEDS FOR IMPLEMENTATION OF CHANGING U.S POLICY ON OCEAN DUMPING: THE MUNICPAL AGENCY VIEW

by

Douglas A. Segar*

Abstract

United States environmental policy is changing rapidly toward the view that the ocean is an appropriate place to dispose of certain wastes of our society. Effluent and treatment sludges from urban sewer systems must be considered as among the most important of such wastes.

During the past decade it has been national policy that the only municipal waste discharged to the aquatic environment should be "secondary treated" effluent. However, there is mounting scientific evidence of the ability of the ocean to safely assimilate effluent streams at other than secondary treatment levels, as well as the sludges generated in wastewater treatment plants. In addition sludges cannot be disposed of safely on land in all cases. These factors have led to two major recent changes in U.S. policy: the Section 301(h) exemption from secondary treatment requirements for marine discharges, and the determination that ocean dumping of sewage sludge should be continued after the 1981 ocean dumping deadline.

In order that ocean waste disposal can be carried out in an environmentally acceptable manner, there is a need to determine the assimilative capacity of coastal marine ecosystems. Assimilative capacity, we believe, should be defined for a given site and disposal technology as the rate of introduction of wastes which cannot be exceeded without unacceptable adverse effects. Assimilative capacity determination will require benefit/risk/cost analyses for each waste and disposal site, comparing available ocean disposal options with available land-based options.

The most critical piece of any benefit/cost/risk analysis is the risk analysis. Risk analysis techniques are very poorly developed at present and must be improved. In addition the use of risk analysis techniques will present significant problems in public perception and education since the calculated risk of any option will never be zero.

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Several other critical research and development areas need to be addressed in support of continued use of the oceans for waste disposal. These include: innovative treatment processes for municipal waste, the technologies of disposal from barges and pipelines, bioassay and bio-accumulation testing protocols, up-to-date inventories of all sources of critical pollutants, controlled studies of municipal wastewater and sewage sludge ocean disposal using the best research techniques available, and public information improvements.

It is important that equal consideration be given to all media as possible waste disposal options. In particular, municipal wastewaters and sewage sludge are of probable benefit as a fertilizer to enhance ocean productivity.

I was asked to give this talk at a relatively late moment for individuals who have more knowledge of the real problems faced by New York City, the political problems of implementing so-called "alternatives" to ocean disposal. I am not going to be able to give you as much gory detail as Francis X. McArdle* would have been able to, about the problems of disposing sewage sludge on the land. But I think that I can certainly give you some insight in that area. I intend also to discuss briefly the problems that we as contractors to the city are having in developing their special permit application for ocean dumping.

Although I am here representing New York City, I am also representing another body of agencies, a nationwide body of agencies that was formed several weeks ago, the Conference of Coastal Agencies. At the present time the members of this conference are: Anchorage, Alaska; Orange County, California; San Diego, California; Hampton Roads, Virginia; Middlesex and Passaic Valleys, New Jersey; New York City; and South Essex, Massachusetts. This is a range of municipal waste treatment agencies from around the entire nation, and we expect the number of members to more than double within the next month or so. All these agencies, bar none, have considerable problems implementing either ocean discharge of their treated effluents or disposing the sewage sludge generated from the treatment processes; problems that promise to become considerably worse in the future.

All these agencies are aware of the ongoing process whereby the ocean disposal option is being reopened, and all of them are very concerned that this be done in an appropriate manner. They do not want to use one alternative for five years only to find it closed to them and find they are required to go back to another alternative

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because there is yet another environmental scare. These agencies are interested in seeing the ocean disposal option reopened, but they want it to be done in a responsible manner. They want the relevant environmental research and monitoring studies to be performed, and most of these agencies are quite prepared to provide funds from their own budgets to perform the necessary studies that may be needed. That is quite a switch. Rather than asking for federal dollars, these agencies are quite happy to give their own.

Integrated Waste Mangement Decisions

Yesterday, we heard a lot about the uncertainties in our knowledge of the environmental impacts of ocean disposal, and I think there was a rather too large an emphasis on ocean dumping. In fact, there are similar uncertainties associated with all of the land disposal options. The problems that we perceive with ocean disposal, the unknowns, the potential impacts that could occur if our worst fears were to come true, are all equally present with each of the other disposal options. Therefore, I would challenge you to think in a much more integrated fashion about this entire problem. This is not simply a problem concerning the oceans. This symposium has critically examined many aspects of the concept of assimilative capacity of the oceans. Assimilative capacity is just one piece of information that is used in a waste management decision.

Several of the agencies in the New York-New Jersey area are currently proceeding with site designation processes for composting plants and for various facilities such as dewatering plants. They are holding the public hearings which are some of the most exciting and emotionally charged that I have ever experienced. Local political managers are under enormous public pressure not to put their sewage sludge in anybody's backyard. Anybody's backyard is generally defined as anywhere where people can see, walk, run, ride, or swim. So there is no ideal place where sewage sludge or effluent can be placed.

In addition, there is also a considerable economic factor involved. Consider, for example, an agency currently providing only primary treatment of its effluent and dumping its sludge in the ocean. When that agency implements secondary treatment and its treatment plant goes on line, the sewer and water rates will typically double. Within several years, if the ocean disposal option were closed to them, this agency would have to add an interim land-based disposal plant (probably a composting facility) and, if that plant was added, the rates would increase by another 50 percent. Later down the line they would have to add a long-term land-based disposal plant, probably an incinerator. If that were implemented the rates would be about four times what they are right now. So, there is a considerable amount of money involved in moving to land-based disposal options, and I think that is something that we all ought to have in mind. It is not a trivial thing at all.

One of the problems that we are facing now, in looking at the ocean as an option again, is that over the last 10 years it has been national policy that nothing shall go in the ocean that comes from a sewage treatment plant unless it is "secondary or better treated" effluent. In consequence, during this period no funds were made available for research that needs to be done if we are going to decide whether we can dispose materials safely in the ocean, whether in fact, what we are doing now is totally safe. There are a lot of unknowns. I think that we would be the first to acknowledge that.

Assimilative Capacity as a Rate

One of the things, of course, that we are talking about in this symposium is the assimilative capacity concept. I am afraid Ed Goldberg stole my thunder yesterday when he agreed to call it a rate, because it really is a rate and not an amount.

The concept of assimilative capacity as an amount, I believe, takes us back to the old bathtub theory, that you put the waste in there and it fills up until it overflows. That clearly is not the way oceans work, and I think NOAA has finally acknowledged that. In recent testimony, NOAA officials have pointed out very clearly that since they have not seen any change over the last few years in contaminant concentrations in the New York Bight ecosystem, at least not within their ability to measure, that there is some dynamic equilibrium that exists there.

Another consideration in the assimilative capacity concept is that sewage sludge is 99 percent natural. It consists primarily of perfectly natural organic compounds. It contains toxic metals (which occur naturally in the environment) and some synthetic organic compounds only in trace quantities.

When you put sewage sludge or sewage effluent particles in the ocean they do not remain discrete particles. They change. They degrade. They move around. They get eaten by organisms, and so they do, in the truest sense, become assimilated. After an appropriate length of time has elapsed for the degradation processes to modify the organic material, the particles are, in fact, indistinguishable from natural material in the ocean. That is, I think, truly what assimilation means.

If we are going to use the assimilative capacity concept, I believe very strongly that it is counterproductive to attempt to define assimilative capacity in a technically precise manner; that is, to establish an end point or end points that are specific, such as we have in the secondary treatment process in which a specific percentage removal of the particulates is required. I think that this can only lead to more trouble. The materials we are dealing with are very

complex. There are a number of different compounds, metals, and other contaminants in sewage sludge. So what we decide is the assimilative capacity today may not be what we decide is the capacity tomorrow when we know more about, for example, the behavior of PCB's. The assimilative capacity is really a dynamic thing. It is something that we have to decide almost on a day-to-day basis.

I want to give you a feeling for where this leads us in terms of the uncertainties in management decisions. I want to review briefly what we are doing for New York City for their ocean dumping permit applications, specifically the multimedia benefit/risk cost analysis.

One of the components of that analysis is an assimilative capacity determination. In determining risk, it is necessary to know at what rate you can introduce materials into the oceans without incurring some phenomenon that is unacceptable. So the assimilative capacity is just one piece of the benefit/risk cost analysis.

We currently are examining the data that is available to do this risk analysis in a technically precise manner. We have been doing it for land-based alternatives and for the ocean alternatives. Looking at the available data and information and the difficulties in establishing the analysis procedure, we decided immediately that it is not possible at this point in time to do more than address the human health risk problems, the key part of the analysis. Risks to the environment other than man are simply too poorly understood to enable quantitative cross media analyses to be made. To establish a human health risk factor three pieces of information are needed: the population at risk, the average exposure level from the material that you are disposing under the given scenario, and the probability of occurrence of health effects. To continue the risk analysis to address environmental impacts we would need to know all these things for each of the biological components of the ecosystem. We are certainly a long way from having that kind of information. Even human health risk analysis must incorporate an exposure calculation for each chemical, for each medium, and disposal scenario. So a tremendous amount of information is needed. Data related to ocean disposal we find to be more complete than that for most land-based alternatives. There is virtually no information that we can use to establish exposure levels of the population through any land application whether it be composting or strip-mine reclamation of sewage sludge. However, there is reasonably good information for incineration options.

In performing these risk analyses there are a number of things that have become clear. First, when you perform a risk analysis in a complex environmental situation, the range of uncertainty in the answer obtained is zero to infinity. All of the possible things that you may not know about can never be taken into account, and so, anytime you calculate a number it has that potential uncertainty.

You have to accept that you can be wrong. You also have to accept that we are going to have very large social acceptance problems with the results of human health risk analysis. Human health risk analysis results in an estimate of the number of deaths in the human population, the number of pathologies that are created by a particular disposal scenario, and this number is never zero. No matter which option you choose, whether it be the ocean, whether it be the 106-mile site, whether it be the middle of the Sargasso Sea, the number is never zero. So we are going to have to face the prospect of going to the public and telling them that the option that we have chosen is going to kill, for example, 25 citizens. Now it may be better than killing 2,000, but it is going to be a very difficult thing to go out there on the streets and tell John Q. Public that you are going to go this route. He is going to ask if he is going to be one of the 25.

We ought, therefore, to recognize that by adopting a risk analysis and multimedia comparison-based management scheme we are setting ourselves up for a whole series of very difficult problems using information from that analysis. I think these are much more important than the problems of performing the analysis itself. I would urge that in any study of how and why we should measure the assimilative capacity of the ocean, these factors be taken into account.

New Reseach Perspectives Needed

I would like to emphasize that the problem of sewage sludge disposal is only a small piece of a much larger problem that has not been addressed historically in a rational manner. Our wastewater treatment processes are largely archaic. The processes we are using now go back several hundred years, at least in concept. In essence we have chosen to use certain technologies to treat our wastes and, therefore, have certain end products which we wish to dispose in the ocean or on the land or elsewhere. One of the most important things we need to do is to step back from where we are today and not to look at the ocean as being a disposal environment needing the same sort of treatment technologies as the freshwater aquatic environment. For example, it seems entirely possible that if we were to go back and look at the most appropriate treatment process for sewage sludge in the context of an assimilative capacity measurement, we might very well decide that nothing more than simple screening of sewage for ocean disposal, plus some new process that would kill off pathogens, might be the most cost-effective method to use and might, in fact, be the least environmentally harmful. I think that ocean waste disposal consideration then becomes a much larger problem than just deciding what we are going to do with the wastes we now have. We also have to go back and decide what we are going to do with those waste streams to optimize them to the available waste disposal options.

There are many important research areas that have not been addressed mostly because of a presumption that ocean disposal would end. I will list some of these briefly.

I was interested to hear mention of whether we can, in fact, discharge below the pycnocline. This is precisely one of the technology studies that we need before deciding whether certain sewage sludges can, in fact, meet the criteria that are embodied currently in federal regulations. There are certain scenarios under which some sludges, if disposed in the surface layers, would not pass those criteria. Yet for the same sludge there are scenarios that would allow them to pass the criteria if they are discharged below the pycnocline.

One of the problems with pipeline discharge is that there is a zone around the end of the pipe where there is significant benthic alteration. We need to consider placing the end of the pipeline away from the bottom; simply suspending the pipeline somewhere in midwater. These are the types of conceptual technology studies that have never been carried out, and I think they are areas that we have to start investigating.

I will mention briefly the bioassay/bioaccumulation study problem. We, personally, feel reasonably confident that we can live with the current bioassay/bioaccumulation testing processes as far as sewage sludge is concerned. However, we do not think that they are relevant to what happens in the real world, and I think there has to be some attention paid to just exactly what those testing procedures mean.

Inventories. One of the most useful tools in managing assimilative capacity of the ocean is the knowledge of exactly how much waste is going in and where it comes from. We do not keep that information routinely. The NOAA-MESA New York Bight Project has funded a large study to get that information for the New York Bight and has updated it once. In itself this inventory is probably the major driving force behind the change that we are now seeing back towards ocean dumping, simply the realization that the ocean dumping is a very, very small proportion of the total impact. We need to keep an inventory of all of these sources on a continuing basis.

Experimental studies. We feel that there have never been adequate experimental studies of controlled discharge of materials, such as sewage sludge, into the ocean. We have performed research mostly on sites where discharge has taken place historically over a number of years. There are some exceptions. There is some work in Southern California on a before-and-after basis. That work generally shows that we do not have too much of a problem. It would be appropriate, if we are going to dispose of these materials in the oceans, to continue these experimental studies. We should use the knowledge

gained from technology studies to decide whether in fact we are just going to run a pipeline out exactly the way we have in the past, with a before-and-after study, or whether we are going to modify the pipeline during the study and try to figure out which is the best way to design a pipeline, where is the best place to put it, how it compares to a barge, whether to put it under the pycnocline or above it. These are the sort of questions, I think, that can only be answered by experimental studies.

Public information. Again, this is an area which is sadly neglected. We have many problems with the general public who obviously see sewage sludge and sewage materials, anything with the word "sewage" in it, as being rather nasty stuff. It is an aesthetically displeasing term, and yet it is a very natural material. Rather than perpetuating the emotional myths that surround "sewage" we ought to pay careful attention to educating the public as to exactly what the disposal options are.

Finally, I was interested in the discussion about eutrophication, somewhat gratified by it, too, since as I coauthored a paper in 1975, in which eutrophication of the New York Bight was discussed (Segar and Berberian, 1976).[1] I believe that there are limited areas of the coastal oceans that suffer from eutrophication. However, there are other areas of the coastal oceans where waste discharge, according to the best evidence we have, has been beneficial. Fisheries productivity in the North Sea, for example, as best we can tell historically, has doubled as the population in the North Sea has risen and as the nutrient inputs from treatment plants have risen. We need to change our philosophy from one that says let us choose a place in the oceans and dump this material and hope that nobody sees it, to one in which we decide that that material is potentially beneficial in the oceans just exactly the same way as it is on the land. There is no reason why we could not use sewage materials, suitably treated, as a fertilizer in the oceans, just as we are using compost on the land. In fact, many of you who are familar with marine chemistry and geochemistry know that there is significant information available that would suggest that we may have fewer problems with trace metals in the ocean than we do on the land. We do not have enough information at this point to make that determination absolutely, but it certainly is a possibility that we should keep in mind as we continue the process of learning to utilize the assimilative capacity of the oceans during the next several years.

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INDUSTRIAL VIEWS ON OCEAN DISPOSAL

by

Richard Sobel*

Abstract

Ocean disposal for selected wastes can be the most environmentally sound and cost-effective method for eliminating them. Mineral acids and inorganics have been successfully disposed of in the ocean without unreasonable degradation. As recommended in a 1981 report by the National Advisory Committee on Oceans and Atmosphere (NACOA), the ocean should be examined further with emphasis on wastes it can reasonably accommodate rather than on wastes we can force to another medium. The impediments to use of the oceans for disposal have been primarily political rather than technical considerations, and have forced increased efforts for not only desirable reductions of wastes at their sources but also for less desirable land-based alternatives. There are also jurisdictional problems between laws that have led to land-based alternatives for the sake of compliance with one law without consideration of the best overall solution to a problem. Now that each environmental medium is regulated by a law, it is time to study carefully how the ocean can take its proper place among these media for disposal of certain of society's wastes.

Introduction

Everything has to be somewhere. A number of people have said it in different ways in the last day or two. We take materials from one part of nature, use it one or more times, change its physical and chemical nature, then eventually put it back somewhere in nature. We have some choices as to the chemical and physical nature of the materials (we are stuck with the Periodic Table) and as to the pathways used to return the materials. One pathway is what the Clean Water Act (CWA) calls waters of the United States, including rivers and streams. One repository is the ocean. The Marine Protection, Research and Sanctuaries Act (MPRSA) expressly calls for regulation of ocean dumping. However, Environmental Protection Agency (EPA) policy, public and political pressures, and the perception that placement of wastes on the land and in other environmental media was generally an acceptable alternative, has eliminated most ocean disposal.

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There is a growing body of knowledge and concern about the problems associated with land disposal, particularly the effects on groundwater. The extreme difficulty that EPA has encountered in developing land disposal regulations under the Resource Conservation and Recovery Act (RCRA) is one manifestation of these problems. If the shape of the proposed RCRA land disposal regulations is any indication, there will be few landfills in the country that will meet the standards, thus putting increased pressures on the use of the ocean for disposal of selected materials. In fact, EPA stated in Feburary, 1981, in the preamble to the proposed Part 264 rules under RCRA that "EPA views land disposal as the least desirable method of hazardous waste management."[1] In the May 26 Federal Register, they shifted their position on land disposal by saying that wastes should be directed to "environmentally superior options." They mentioned ocean disposal as one of those possibilities, and they also stated their intent to consider intermedia trade-offs. So we may be seeing an encouraging shift in policy.

We now have environmental laws covering every part of nature--land, air, surface water, groundwater and oceans. Historically, as each statute was implemented, it chased waste materials to another part of the environment. Our society will continue to produce materials which require disposal. Many of these materials cause only insignificant or theoretical harm when directly disposed of in the ocean. There are probably others that, with a net benefit to our society, ought to be directly disposed of in the ocean rather than in a stream.

We believe that the state of our awareness is right to identify these materials and the conditions under which ocean disposal should be used. Not only the technical, economic, and environmental factors, but also the statutory and political impediments needed to be examined if we are to get the most effective use of each part of our environment. Much can be done within the existing framework to make more reasonable use of the ocean.

My remarks today are on behalf of the Chemical Manufacturers Association (CMA) and most of the information cited is from the public record. Some of my own opinions are included based on my discussions with some of the people involved.

The Law

The Marine Protection, Research and Sanctuaries Act of 1972 (P. L. 92-532) states United States policy is to regulate "ocean dumping" and to prevent or limit the dumping of materials with adverse effects. Title I deals with the regulatory program and is the section that industry is most concerned with. It says: "the Administrator may issue permits ... where the Administrator determines that such

dumping will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." Factors to be considered include "the need for the proposed dumping" and "appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon considerations affecting the public interest." Title I does not say that ocean dumping is to be the method of last resort, nor does it say that ocean dumping is to be allowed only if it is the least environmentally damaging alternative.

Part 227 of EPA's regulations was developed under this mandate and provides criteria for the evaluation of permit applications for ocean disposal. If a material meets the environmental impact criteria, which deal with the quality of the waste, its levels of contaminants, and its toxicity and other effects on the ocean, a permit will be issued unless (1) there is no need and alternatives are available; or (2) there are unacceptable adverse effects of the disposal on aesthetic, recreational, or economic values; or (3) there are unacceptable adverse effects on other uses of the ocean. This has been translated, for evaluation of an alternative, into: Is it technically feasible? Is it environmentally acceptable? (Can you get air, water and solid waste permits?) And is it economically reasonable? In most cases, EPA has stopped at--is it technically feasible?

EPA has not yet had to make a permit decision on the economic reasonableness of land-based alternatives. They have been granting or denying permits based solely on environmental criteria. However, we believe that, even in a situation where the environmental impact criteria are not met or where a land-based alternative to ocean disposal has a lower overall environmental impact than ocean dumping, economics need to be factored into the decision to grant or deny a permit.

This approach is supported by the National Advisory Committee on Oceans and Atmosphere (NACOA) in its second recommendation for an integrated approach to waste management: "... even if the risk were somewhat greater for ocean disposal, significantly disproportionate costs could justify the granting of the ocean dumping permit."[2] This view is also supported by the recent (April 14, 1981) opinion of Judge Sofaer of the United States District Court, Southern District of New York in The City of New York v. The U.S. Environmental Protection Agency in which he states that the language of the Act requires a balancing of all the statutory factors, including costs, when determining what "unreasonable" means (as used in this Act).

The Regulations

The regulations require reports and demonstrations in most of the following areas:

Subpart B: Environmental Impact. This is, in essence, where undue degradation or endangerment of the marine environment are defined. It lists prohibited materials, allowable trace contaminants, metals, organohalogens, oil, etc., in terms of concentrations and bioassay tests; sets limits for specific wastes such as immiscible, low-level radioactive, pathogens, acids and alkalies, and deals with disposal rates, quantities insoluble wastes, dredged materials, and containerized wastes.

Subpart C: Need for Ocean Dumping. This is a key section that says how alternatives will be evaluated. Pertinent criteria include costs and environmental impacts as well as pretreatment and process change possibilities. Practicable alternatives are defined as those with reasonable incremental cost and energy expenditures, not necessarily competitive with ocean disposal.

Subpart D: Impact of the Proposed Dumping on Aesthetic, Recreational and Economic Values. This also requires that impacts on economic values be considered. It requires evaluation of trade-offs between land and ocean.

Subpart E: Impact of the Proposed Dumping on Other Uses of the Ocean.

Subpart F: Interim Permits. This requires phase out of practices or compliance by the end of 1981.

Subpart G: Definitions.

Background

In the late 1940s, industrial waste dumped in the ocean was at least 1.5 million tons per year. In 1973, it was up to 5 million tons and in 1979 was down to about 2.5 million tons. This covers the Atlantic, the Pacific, and the Gulf of Mexico. The Pacific has had none since at least 1973. During this period, total dumping of all types of wastes went from about 11 million tons in 1973 to about 9 million in 1979. These figures do not include direct pipe discharges to the ocean under the CWA which, for industry, is on the order of 100 times the dumped volume, and for municipalities is another 10 times higher.

In 1972, there were 122 industrial dumpers. Of these 111 have phased out, withdrawn, or had their permits denied since EPA took over the program in 1973. Six more permittees are due to phase out this

year, leaving five at the end of this year. There are presently three industrial ocean dumping areas in the United States, all in EPA Region II.

What has happened to all those dumpers? Most disposal was of minor volumes and the generators had easily available alternatives, so many withdrew voluntarily. Others were forced by EPA's interpretation and application of the regulations, or by public pressure, by pressure from the states, or by company decision not to risk adverse publicity, to withdraw and to implement alternatives. Some of these took several years to develop and implement. Were some forced out unreasonably? It depends on how you define unreasonable; it would make an interesting thesis subject. One dumper went to land-based incineration, although his ocean incineration test proved environmentally successful, because of the outcry from shrimp fisherman.

What types of industrial wastes used to be dumped? Acid and iron wastes from TiO_2 manufacture, alkaline wastes from organic chemical manufacture, plating wastes, wastes from inorganic processes, from food industries, from textiles, inorganic salts, biodegradable wastes from organics manufacture, wastes from pharmaceuticals, flavors, fragrances, paper, paints, from waste reclaimers.

What types will remain after 1981? Alkaline inorganics containing some organics, acids, and cellar dirt.

Industrial Cases

I would like to present some information on a few cases of industrial ocean disposal which may provide guidance on how to make better use of the ocean.

Case 1

This involves hydrochloric acid which has been disposed of at the acid grounds in the New York Bight since 1962. This is a case where disposal is still proceeding under a special permit, having survived the many hurdles required by the regulations and by public hearings. In summary, ocean disposal of these wastes is economically and environmentally the soundest method and it meets the environmental criteria of the regulations.

The waste is hydrochloric acid. The major impurity is fluoride at about 1-2 percent. The acid is generated as a by-product in the manufacture of halocarbons. A portion of the acid is sold as a commercial grade, but the market is usually oversupplied and not dependable.

Acid disposed of in the ocean in the past eight years has ranged from 23,000 tons to 55,000 tons annually.

Until 1973, permits were issued by the U.S. Army Corps of Engineers. In 1973, the first permit was issued by EPA under the MPRSA. The 1974 permit was a one-year interim permit and required a series of tests and demonstrations to comply with the various parts of the regulations--detailed analyses, dispersion studies, a detailed engineering report examining the alternatives to ocean disposal, bioassay tests. The waste and its disposal in the ocean met the environmental criteria of the regulations.

Subsequent permits required increasingly detailed evaluation of land-based alternatives and refined the testing and reporting requirements. The stated requirements to stay in the ocean were that (1) the discharge not violate the criteria, and (2) an environmentally acceptable alternative was not economically feasible. In other words, the alternative needed only to be permittable under other environmental statutes--it did not have to be environmentally better and it had to be affordable. Finally in 1979, a three-year special permit was issued.

The 1973 interim regulations required that an extensive list of about a dozen land-based alternatives be examined. Each one was considered, but most, for example, incineration and landfill, were technically not feasible for hydrochloric acid.

Four alternatives were examined in great detail. Two involved neutralization of the acid with lime or caustic soda and discharge to nearby receiving waters. In both cases, there would be a large increase in the dissolved solids load, about 78,000 tons per year. In one case, the fluoride ends up in the effluent as a soluble salt; in the other, it would require disposal on the land as 8,000 tons per year of sludge. In both cases, the discharges were environmentally unacceptable to the state. Two other alternatives involved process changes to produce a purer acid to increase its salability. In each case the fluoride ends up as a CaF_2 sludge requiring land disposal. Since the amount of acid upgraded is limited by the market, a sizable portion of the acid would still have to be neutralized or dumped in the ocean. Neutralization has the same dissolved solids problem as the previous two alternatives and the other alternative was environmentally less acceptable than the full ocean disposal case.

I would now like to note the costs of the land based alternatives in this case. Investment costs would be up to roughly $10 million. Operating cost increases over ocean disposal would range, at capacity operation, up to roughly $3 million per year. Cost per ton of unsold acid would increase anywhere from 20 to 50 times that of ocean disposal. Energy costs in terms of additional fuel oil would increase up to 800,000 gallons per year. The environmental costs of the alternatives

were compared to ocean dumping with the result that, both for immediate and long-term effect, ocean disposal had a lower overall environmental impact. Study and support costs for the 1973 to 1980 period, for consultants, special tests, contractors, analyses, monitoring, support at hearings, and such were on the order of $500,000.

Case 2

The waste, in this case, is an alkaline solution of sodium sulfate at about 15 percent strength with less than 1 percent organics. Approximately 100,000 to 300,000 tons per year have been dumped over the past eight years at the 106-mile site (also known as deepwater dumpsite 106 or chemical waste dump site). This permittee went through similar tests, proofs, demonstrations, and detailed evaluations of land-based alternatives including biotreatment, incineration, oxidation, carbon adsorption, steam stripping, extraction, landfill, deepwell injection, and recycling.

A three-year special permit was awarded in 1978 and again in 1981 based on findings that the waste complied with the environmental impact criteria in Section 227 of the regulations and that there was no environmentally acceptable alternative.

Now, some cases where permittees have eliminated ocean disposal or are scheduled to.

Case 3

In this case, wastes from the manufacture of TiO_2 by the sulfate process are disposed of at the acid grounds in the New York Bight. Roughly 2 million tons a year of a water solution of dilute sulfuric acid, ferrous sulfate, and solids are involved. Disposal proceeds under a special permit issued in 1978. A tentative position by EPA Washington was that final effluent guidelines under the Clean Water Act would have to be met even though there was provision for ocean disposal under MPRSA.

The interesting aspect of this case is that the plant was cited by EPA under the Clean Air Act (CAA). This resulted in a consent decree under the CAA which included a revision in the plant's process from batch to continuous to meet the requirements of the CAA. The investment involved for the process change is large, millions of dollars, and the company wanted to be sure that it had time to develop and implement its process and that it had a long-term agreement for continued ocean disposal. Thus, another consent decree was entered into with EPA to phase out ocean disposal by the end of 1989 and reduce free acidity in stages along the way.

The wastes involved meet the environmental impact criteria of the ocean dumping regulations, and I believe the company had previously demonstrated that the land-based alternatives were environmentally less acceptable. In this case, neutralization with lime was evaluated but would result in large gypsum stacks on the land, unless the gypsum could be sold. It is also my understanding that the process change will permit increased recycling of the spent acid, thus permitting compliance with a staged reduction in volume to the ocean.

Case 4

The wastes in this case are generated by several processes, essentially organic chemicals for mining, rubber, water treatment, intermediates, surfactants and insecticides. They were dumped at the 106-mile site under an interim permit. Dumping started in 1968 as the result of an agreement with the state to stop discharging to a waterway and that ocean disposal was the most acceptable alternative.

These wastes, at roughly 150,000 tons per year, had a separable organic phase which was removed about six years ago for burning in an incinerator and was subsequently reduced by process changes. About one-third now goes to a municipal sewage treatment plant, one-third to one of the plant's own wastewater treatment plants, and one-third to an incinerator. So here is one operation that stopped because alternatives were developed. This is an excellent example of how a waste was pushed from one medium to another to satisfy new statutes.

Case 5

In this case, we also have a TiO_2 producer that has been disposing of its acid/iron wastes in the ocean since 1968 because of pressures by state and regional agencies to reduce discharges to a river. This producer switched to a proprietary chloride process instead of the conventional sulfate process by the mid-1970s because of emission problems and in anticipation of the end of ocean disposal. Their waste is a hydrochloric acid/iron chloride waste which was substantially lower in volume than the previous acid/sulfate waste.

This permittee has had special permits since 1978 which require the volume of waste to be reduced from about 300,000 tons in 1980 to about 140,000 tons in 1983. In 1984, the permit requires cessation of ocean dumping. They have installed a facility for the recycle of HCl and recovery of by-product iron chloride which they market as a water treatment chemical. The market is very competitive and the company has had problems in developing sales. They have spent roughly $30 million in developing and installing facilities to reduce ocean disposal. I believe that a major part of the reason for their

continued efforts to reduce ocean dumping through recycle of HCl and sale of iron chloride has been extreme pressure by some states, bad publicity, and adverse EPA regional policy.

Their former practice of ocean disposal met the environmental criteria of the regulations. However, in demonstrating need, the EPA region's interpretation of the regulations was that if there was any land-based alternative there was no need; if there was no land-based alternative, there was a need. The standard for a land-based alternative was--can you get permits?

The economics of the situation are such that the investment for abating ocean disposal would not have been made if normal business criteria were used as the standards.

This company examined at least five alternatives in arriving at their present system.

When you look at three TiO_2 producers: one could not get a permit; one is phasing out of the ocean over nine years; and one has dramatically reduced its ocean disposal and is phasing out over two or three years. All have spent or will spend many millions of dollars. The varied treatment accorded these companies by EPA, the states, and the public has no doubt resulted in cost inequities in the industry.

Costs

Table 1 shows some typical costs for various methods of waste disposal. Most are based on recent quotes or estimates. The incineration costs will vary with the organic chlorine content.

Table 1

Typical Disposal Costs

	$ / TON
Chemical landfill (drums)	200 - 500
Chemical landfill (bulk)	60
Sanitary landfill (bulk)	50 - 200*
Incineration (C-H-C)	250 - 600
Incineration (PCB's)	4000*
Deepwell	20 - 50
Acid neutralization & sludge disposal	50
Municipal sludge (dry ton)	72 - 200

*Including transportation

Landfill costs will also vary with the nature of the waste. The acid treatment cost will vary considerably depending on acid strength and volume of solids generated. The sanitary landfill and PCB costs include transportation. Transportation must be added to the others and may be significant depending on the distance involved. It is not unusual to ship a waste 500 miles to a contract disposal firm.

Summary

According to the 1981 NACOA report, EPA policy has been that no ocean dumping permit will be issued when any land-based alternative exists. This statement confirms industry experience. The Chemical Manufacturers Association agrees with NACOA that this policy needs to be revised. Neither the law nor the regulations support this policy.

The environmental statutes, particularly the Clean Water Act, need to be examined to see if they need changing to allow ocean disposal to be considered as an alternative to disposal in other media or as an acceptable technology. Different parts of industry will come down on both sides of this question depending on what their current practices are and on who would get a competitive edge.

The public needs to be educated to the fact that selected wastes can be safely disposed of in the ocean and that it is the best place to put certain wastes. This is an extremely difficult problem because there always seems to be a special interest group intent on protecting that part of the environment of interest to that group. The difficulty in siting new hazardous and other land-based waste disposal facilities is a prime manifestation of this type of problem.

There are wastes that, from a technical point of view, can be dumped in the ocean in conformance with the law, in addition to those wastes that will be permitted to be dumped after 1981. Studies appear warranted to determine which ones. Laboratory tests prescribed by the regulations may not be totally accurate in their predications of impact. Some provision in the regulations for a trial dumping permit would probably be useful to give EPA the flexibility to permit a full-scale field test for the purpose of measuring actual impacts.

Industry should be allowed to examine its alternatives before applying for a permit and should be allowed to make its own economic decisions. We believe that if the ocean dumping meets the environmental criteria of the regulations, a permit should be issued. Certainly if ocean disposal meets the environmentally more acceptable than the alternatives, it should be permitted. Some changes in the regulations may be necessary here.

Finally, the existing framework would allow greater volumes of wastes and new permittees into the ocean if, as Judge Sofaer has ruled, EPA considers all factors on balance, that is technical, environmental, and economic.

REFERENCES

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IMPACTS ASSOCIATED WITH THE DISCHARGE OF DREDGED MATERIAL: MANAGEMENT APPROACHES

by

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Abstract

With few exceptions, impacts of aquatic disposal of dredged material are mainly associated with the physical effects. These effects are persistent, often irreversible, and compounding. From a geochemical viewpoint, contaminant releases are usually limited to nutrients with negligible releases of toxic metals and hydrocarbons. Biochemical interactions are infrequent with no clear trends, and elevated uptake of toxic metals and hydrocarbons are usually negligible.

Land-based disposal alternatives appear to offer limited protection in relation to human impact when compared to aquatic discharge and, moreover, are often excessively costly. Land-based disposal methods often drastically change the geochemistry of the dredged material with a subsequent enhanced release potential of chemical constituents. Land sites are usually located in or near highly productive nearshore areas or adjacent to or in contact with groundwater aquifers.

Even highly contaminated dredged material can be disposed in open water if sufficient care is exercised in site selection to ensure that the material is isolated from the biotic zone of the marine system. This approach involves disposal site management using capping techniques or locating disposal in abiotic areas. Dredged material should be regarded as a highly manageable material for disposal in the marine environment.

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Introduction

At the beginning of the 1970s, the concern over the environmental impacts of dredging to maintain navigable waterways and harbors and the subsequent disposal of dredged material reached the stage where new domestic legislation was necessary. It was recognized that the technical rationale on which earlier legislation was based was inadequate; existing information was limited to site-specific studies that permitted only inferences that the open-water disposal of contaminated dredged sediments presumably must be harmful to the environment. Much has been learned during these past 10 years about the disposal of dredged material with the majority of the findings direct products of the U. S. Army Corps of Engineers (CE), Dredged Material Research Program (DMRP).[1, 2, 3]

Through the years, domestic and international navigable waterways have played a vital role in the nation's and the world's economic growth. The CE, in fulfilling its mission to maintain, improve, and extend waterways of the United States, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material average about 300,000,000 cubic yards (186,000,000 dry tons) in maintenance dredging operations and about 80,000,000 cubic yards (48,000,000 dry tons) in new work dredging operations.[1]

Between 1 to 10 percent of the sediments in waterways and harbors have become contaminated due to man's industrial, urban, and agricultural activities, and concern has developed that dredging and disposal of this material may adversely affect water quality or aquatic organisms. A number of localized studies were made prior to the DMRP[1] to investigate the environmental impact of specific disposal practices and to explore alternative disposal methods. However, these studies did not provide sufficient definitive information on the environmental impact of current disposal practices, nor did they fully investigate alternative disposal methods. As a result, the CE was authorized by the Congress in the 1970 River and Harbor Act to initiate a comprehensive nationwide study to provide more definitive information on the environmental impact of dredging and dredged material disposal operations and to develop new or improved dredged material disposal practices. The U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, was assigned the responsibility of developing and managing the DMRP. A detailed planning document,[1] description of the technical and management structure and summary of the programs,[2] and a publication index and retrieval system[3] can be found in the indicated references.

The DRMP was designed to be as broadly applicable as possible on a national basis with no major type of dredging activity or region or environmental setting excluded. It thus resulted in methods of evaluating the physical, chemical, and biological impacts of a variety of disposal alternatives--in water, on land, or in wetland areas--and produced tested, viable, cost-effective methods and guidelines for reducing the impacts of conventional disposal alternatives. At the same time, it demonstrated the viability and limits of feasibility of new disposal alternatives, including the productive use of dredged material as a natural resource.

To those concerned with national or regional planning, regulation, and policy formulation, there are two extremely important fundamental conclusions that can be drawn from the results of the DMRP. First, there is no single disposal method that may be presumed to be most suitable for a region, for a type of dredged material, or for a group of projects. Correspondingly, there is no single disposal method that may be presumed to result in impacts of such nature that the method can be categorically dismissed from consideration. Put in different terms, there is no inherent effect or characteristic of method that rules it out of consideration from an environmental standpoint prior to specific on-site evaluation. This holds true for open-water disposal, confined upland disposal, habitat development, or any other alternative.

Specific on-site evaluations mean that each project must be considered on a case-by-case basis. It is not technically sound, for example, to make general statements that ocean disposal must be phased out or that all material in the Great Lakes area classified as polluted must be confined behind dikes. To do this would be contrary to research results that have indicated that there can be situations where there is greater probability of adverse environmental impacts from confined disposal than from open-water disposal. Yet, in other situations such as when certain types of contaminants are present, confined disposal may provide the greatest degree of environmental protection.

Implications of this conclusion from a management point of view are fully recognized. Case-by-case evaluations are time consuming and expensive and may seriously complicate advanced planning and funding requests. Nevertheless, from a technical point of view, situations can be envisioned where tens of millions of dollars may have been or could be spent for various disposal methods that contribute to adverse environmental effects rather than reduce them.

The second basic conclusion is that environmental considerations are stronger than possibly any other force in necessitating long-range regional planning as a lasting, effective solution to disposal problems. No longer can disposal methods be planned independently for each dredging operation for multiple projects in a given area. While

each project may require different specific solutions, the interrelationships must be evaluated from a holistic perspective and thought given to replacing particular disposal methods as conditions change. Regional disposal management plans not only offer greater opportunities for environmental protection ultimately at reduced project cost, but also meet with greater public acceptance once they are agreed upon.

It is the general intent of this investigation to demonstrate that no category of disposal method is without environmental risk, reflects the best management practice, or offers the soundest environmental protection. It is further proposed that all specific disposal alternatives be fully investigated during the planning process and be treated on an equal basis until a final decision is made that is based on all available facts. Lastly, it is hypothesized that even the most highly contaminated dredged material can be considered for all disposal alternatives through application of an adequate management plan and that such disposal methods are legally acceptable under domestic regulations and international treaty.

Open-water Disposal

Sediment Geochemistry

Fundamental to understanding the impact of sediment discharge and resuspension on water quality and aquatic organisms is an understanding of how chemical constituents, which may have various effects on aquatic organisms, are associated with dredged sediments.

Sediments may be separated into several components or phases that are classified by their composition and mode of transport to the aquatic environment. Among them are detrital and authigenic phases.

Detrital components are those that have been transported to a particular area, usually by water. Detrital materials are derived from soils of the surrounding watershed and can include mineral grains and rock fragments (soil particles) as well as stable aggregates, associated organic material, and culturally contributed components derived from agricultural runoff and industrial and municipal waste discharges.

Authigenic components are those that are formed in place or have not been transported an appreciable distance. These materials are generally the result of aquatic organisms and include shell material ($CaCO_3$), diatom fustules (SiO_2), some organic compounds, and products of anaerobic or aerobic transformations.

In considering the <u>in situ</u> association with various sediment phases of trace elements in sediments, the water contained in inter-particle voids or interstices must be considered. This is termed interstitial water (IW). In relation to the overlying water, chemical constituents may frequently be enriched in the IW by several mechanisms. Some constituents (metals and some nutrients) are ionically bound to the sediment in several exchange locations; these include the exchange sites of the silicate phase and exchange sites associated with organic matter or trace elements complexed with the organic phase. Man-made organics such as PCB's (polychlorinated biphenyls) may be physically attached to these highly active silicate materials. Only a small amount of these low solubility or slightly soluble constituents is found dissolved in the IW.

Heavy metals are also associated with hydrated manganese and iron oxides and hydroxides that are present in varying amounts in sediment. Another location for heavy metals is in the sediment-organic phase. The metals are incorporated into living terrestrial and aquatic organisms and are relatively stable; however, they may be released into the water column during decomposition. The greatest concentration of most inorganic chemical (excluding some nutrients) constituents is present as an integral part of the silicate mineral structure (earth's crust material) of a sediment.

From the previous discussion of elemental partitioning and for analytical purposes, the following categories of sediment components should be considered.[4, 5, 6]

1. <u>Interstitial water (IW)</u>: an integral part of sediment. IW is in dynamic equilibrium with the silicate and organic exchange phases of the sediment as well as with the easily decomposable organic phase.

2. <u>Mineral exchange phase</u>: that portion of the element that can be removed from the cation exchange sites of the sediment using a standard ion-exchange extractant (NH_4OAc, dilute HCl, NaCl, $MgCl_2$, etc.).

3. <u>Reducible phase</u>: hydrous oxides of iron and manganese as well as hydroxides of Fe and Mn, which are relatively soluble under reducing (anaerobic) conditions. Of particular importance are the toxic metals (As, Cu, Cd, Ni, Co, and Hg) that may be associated with these discrete Fe or Mn phases as occlusions or coprecipitates.

4. <u>Organic phase</u>: that phase or portion of elements considered to be soluble after destruction of the organic matter. This phase contains very tightly bound elements as well as those loosely chelated by organic molecules. An initial extraction by an organic chelate

may be needed to differentiate between the loosely bound and tightly bound elements. (Sands dredged from the Mississippi have little or no organic matter. Areas such as New York Harbor average 4-8 percent total organic carbon.)

5. Residual phase: primary minerals and secondary weathered minerals, which are, for the most part a very stable portion of the elemental constituents. Only an extremely harsh acid digestion or fusion will break down this phase. By far the largest concentration of metals is normally found in this fraction.

A particular element or molecule can then be present (partitioned) in a sediment in one or more of several locations. Possible locations include (a) the lattice of crystalline minerals; (b) the interlayer positions of phyllosilicate (clay) minerals; (c) adsorbed on mineral surfaces; (d) association with hydrous iron and manganese oxides as hydroxides existing as surface coatings or discrete particles; (e) absorbed or adsorbed with organic matter existing as surface coatings or discrete particles; and (f) dissolved in the sediment interstitial water. These locations also represent a broad range in the degree to which an element may be released to the receiving water. This range extends from stable components in the mineral lattices, which are essentially insoluble, to soluble compounds in the sediment IW that are readily mobile. Electrochemical (Eh, pH) changes after disturbing and resuspending anaerobic bottom sediments may result in possible solution or precipitation of many elemental species and should be thoroughly characterized.

A sediment characterization procedure to elucidate the phase distribution of contaminants in dredged material must be applicable to many types of marine and freshwater sediments, both aerobic and anaerobic. To be realistic, sediment disturbance must be minimal. Thus, drying, grinding, and contact with atmospheric oxygen are undesirable. The sediment phases discussed previously were presented in their relative order of mobility and bioavailability. Interstitial water is the most mobile and, consequently, the most available. When contaminants enter a body of water and subsequently sediment particulate matter, the contaminants normally enter two or three factions in varying concentrations but cannot be distinguished from natural levels by a bulk or total analysis.[4, 5, 6, 7]

Laboratory Investigations

Contaminant release. A number of studies of chemical constituent release mechanisms have evaluated conditions that enhance release of toxic metals when the sediment-water geochemical environment is drastically changed.[8] As an example, significant release of zinc to

the water-soluble phase was shown to occur at pH 5 under oxidizing (positive Eh) conditions. It must be emphasized that these acid-oxidizing pH-Eh conditions do not normally occur in open-water disposal --as anaerobic sediments normally remain near neutral pH--and the oxidation processes that occur in the water column are not such as to result in an acidic condition.[5, 7, 8] Subsequently, after it settles, sediment normally returns to an anaerobic and near-neutral pH condition. On the other hand, if this sediment is placed in an upland containment area where oxidizing conditions can occur for a year or more and the sediments are high in total sulfide (common in many fine-grained estuarine sediments), the pH can become acidic and result in significant release of some contaminants to the water-soluble phase.[4] Therefore, judicious selection of the disposal mode (open water versus upland) and an understanding of the long-term implications of either disposal mode are very important. These preliminary discussions only hint at the complexity of chemical constituent distribution and interaction within and among sediments; for a detailed discussion of sediment chemistry, biological, and water quality interrelations, the reader is referred to references 5, 7, 8, 9, 10, 11, and 12.

Results of laboratory investigations of the impact of disposal on water quality show that ammonium, manganese, iron, and ortho-phosphate were released from anaerobic sediments during simulated disposal and initial mixing and after the sediment had settled to the bottom.[7, 8, 12, 13] It was found, however, that the sediments scavenged or cleaned the water column of numerous toxic heavy metals and nutrients when contaminated fine-grained harbor sediments were dispersed in a water column. No release of chlorinated hydrocarbons to the soluble phase was detected during the simulated open-water disposal of dredged material from a broad selection of marine, freshwater, and estuarine sediments.[8, 12, 14] After the sediments had settled and formed a new sediment-water interface, several constituent release and immobilization patterns were detected.[8, 12, 13, 14] Release from the sediments to the water column, with the exception of iron, manganese, and some nutrients, was extremely small. Several toxic metals were released in concentrations less than one part per billion from either contaminated harbor sediments or noncontaminated sediments. It must be emphasized that these processes and transformations occur naturally in all sediments at somewhat similar levels and do not appear to be of a significant nature.[8, 12, 13]

Studies of chemical constituent release mechanisms have evaluated conditions that enhance release of toxic metals when the sediment-water geochemical environment is drastically changed.[11] The significant release of zinc, mercury, and cadmium to the water-soluble phase was shown to occur at pH 5 under oxidizing (Eh) conditions. These acid-oxidizing pH-Eh conditions, as previously mentioned, do not normally occur in open-water disposal as anaerobic sediments remain

near neutral pH and the oxidization processes that occur in the water column are not such as to result in an acidic condition.[11] Release was not shown to occur under conditions simulating an open-water disposal site. Upland containment, where oxidizing conditions can occur after a year or more, of sediments that are high in total sulfide results in acidic pH conditions and significant release to the water-soluble phase.[11, 15]

Long-term release studies were conducted in 32 locations of a large number of sediments representing a broad variation of geography and pollution in marine, estuarine, and freshwater areas.[16] The sediment-water systems were evaluated under various conditions. Under conditions likely to prevail at aquatic disposal sites, organic carbon, orthophosphate, and zinc exhibited consistent net releases to the water column. Even so, the sediments (some highly contaminated) would not be expected to cause significant water quality problems.

The preceding observations and numerous other geochemical transformations of an extensive list of sediment constituents are discussed in detail in references 5, 7, 8, 9, 11, 12, 13, 14, 15, and 16. Investigations for the development of regulatory testing criteria have shown conclusively that no relationship exists between sediment characteristics determined by the so-called "bulk" or "total sediment analysis" and the effect of aquatic disposal on water quality or aquatic organisms.[4, 5, 6, 7, 9, 11, 12, 13, 14, 17, 18] These investigations have, however, shown that the elutriate test,[19, 20] a water leach of the sediment, can be used to predict water quality perturbations and water column biological impacts.[5, 6, 7, 9, 17, 18]

Biological effects. The previously reported research has suggested little release of most chemical constitutents from dredged material, further emphasizing the need for determining the biological effect of chemicals associated with the sediment solid fraction. Regardless of the chemical nature of the solid fraction, the physical effect on various organisms must also be thoroughly evaluated. Investigations determining the effects of turbidity (suspended dredged material) on aquatic organisms, the ability of organisms to migrate vertically through deposits of dredged material, the uptake of sediment-sorbed metals and pesticides, and the biological effects of sediments contaminated with a wide range of pollutants are discussed in the following paragraphs.

Turbidity studies[21, 22, 23, 24] conducted with adult marine, estuarine, and freshwater organisms have shown lethal concentrations of suspended dredged material to be an order of magnitude or higher than maximum water column concentrations observed in the field during dredging operations.[25, 26] In these laboratory investigations, the mortality of select organisms was demonstrated in concentrations of suspensions of dredged material exceeding 2 to 20 grams per liter (2,000-20,000 ppm) at 21-day exposure times. Field observations have

shown turbidity or suspended particulate levels to be less than one gram per liter (1,000 ppm) for exposure times of only hours. Based on these and other observations, it was concluded that the physical effect of turbidity from dredged material discharge in open-water would be of minimal biological impact. Consequently, the primary impact of turbidity is an aesthetic characteristic and must be controlled and treated as such. The only exception to this conclusion would be the sensitive coral reefs of tropical regions where low concentrations of suspended particulate could significantly affect large areas.

Other physical impact investigations evaluated the ability of estuarine and freshwater benthic organisms to move vertically after being covered or smothered by various loadings of dredged material.[27] The laboratory evaluations demonstrated that selected organisms (clams, crabs, and benthic worms) were able to recover through a covering as thick as one meter or were smothered by as little as a covering of a few centimeters, depending on the type of dredged material. The organisms generally recovered through the deposits in a matter of hours, and minutes in some cases. These studies investigated combinations of sand dredged material deposited on mud and sand substrates and mud dredged material on mud and sand substrates.[27] The most drastic biological impact was noted when unlike dredged materials were placed on either substrate. Impacts were maximum where a sand dredged material was placed on a mud substrate and covered normally mud-dwelling organisms that were not suited for mobility through the sand. The same was true where sand-dwelling organisms were quickly smothered by a mud covering. Judicious selection of disposal sites where sand is placed on a sand bottom or mud on a mud bottom is imperative to minimize immediate or long-term physical impact at the site.

Site-specific field studies demonstrated that benthic organism recolonization of dredged material mounds formed during disposal was relatively rapid, and the processes were attributed in some part to vertical migration.[28] However, a significant number of organisms also may be brought out with the dredged material and affect recolonization patterns.

Metal availability and accumulation studies were conducted by Neff et al., using the clam Rangia cuneata, the grass shrimp Palaemonetes pugio and Palaemonetes kadiakensis, and the worms Neanthes arenaceodentata and Tubefex sp.[29] Test sediments, as shown in Table 1, were taken from Texas City and Corpus Christi, Texas, ship channels (15 and 30 parts per thousand salinity, respectively) and the Ashtabula River in Ohio (fresh water). Metals routinely measured were iron, manganese, copper, cadmium, nickel, lead, zinc, chromium, and mercury.

For most metals studied by Neff et al., as presented in Table 2, uptake by organisms was not evident. However, when uptake was shown to occur, the levels often varied from one sample period to another

Table 1

Concentration of Metals in Sediments, Site Water, and Sediment Elutriates[29]

a. Total Sediment Concentration, mg/kg of dry weight

Metal	Texas City Channel	Corpus Christi Channel	Ashtabula River
Copper	48	120	37
Chromium	188	82	75
Cadmium	2.4	21	4.8
Iron	14,500	12,000	25,000
Nickel	48	17	52
Manganese	570	257	356
Lead	41	316	42
Zinc	161	4,055	315
Mercury	0.6	18	1.1

b. Elutriate Concentrations, μg/ℓ

Metal	Texas City		Corpus Christi		Ashtabula	
	Site Water	Elutriate	Site Water	Elutriate	Site Water	Elutriate
Copper	20	9	9	3	9	6
Zinc	44	28	325	1700	85	50
Manganese	32	5800	22	890	3	550
Iron	44	52	10	20	15	650
Lead	1	1	2	6	1	1.5
Chromium	1	6	<5	<5	<5	<5
Cadmium	<1	<1	<1	<1	<1	<1
Nickel	85	75	11	9	21	20
Mercury	0.05	0.10	0.05	0.55	0.11	2.85

Table 2

Summary of Bioavailability of Sediment-Adsorbed Heavy Metals to Benthic Invertebrates During Short-Term Exposures[29]

Metal	Texas City Sediment			Corpus Christi Sediment			Ashtabula Sediment		
	Rangia	Palaemonetes	Neanthes	Rangia	Palaemonetes	Neanthes	Rangia	Palaemonetes	Tubifex
Cadmium	0	-	0	0	0	0+	0	0	0
Chromiun	0	+	+	0	0	0	0	0	0
Copper	0	0	+	0	-	0+	0	0	0
Iron	0	+	0	0	+	0+	+	+	+
Mercury *							0	0	
Manganese	+	+	0	0	-	0	0	0	0
Nickel	0	-	0	-	-	0	0	-	0
Lead	0	0	+	0	+	+	+	0	+
Vanadium *							+	+	
Zinc	0	-	0	0	+	0+	0	-	-

+ = Statistically significant effect of exposure, and/or the interaction of exposure with salinity, time, or both on the concentrations of the heavy metals in the animal's tissues.

- = Statistically significantly inverse effect of exposure, and/or the interaction of exposure with salinity, time, or both on the concentrations of the heavy metals in the animal's tissues (control animals had significantly higher metal concentrations than did sediment-exposed animals).

0 = Exposure to sediment did not contribute significantly to the concentrations of the heavy metal in the animal's tissues.

0+ = Replicate experiments with Neanthes exposed to Corpus Christi sediment at 30 o/oo gave opposite results.

*Statistical analyses of mercury (Hg) and vanadium (V) were only performed on tissues of Rangia and Palaemonetes exposed to Ashtabula sediment in freshwater. Hg analyses for other tests were at or below detection limits with few exceptions and V was only studied for Ashtabula sediments.

and were quantitatively marginal, usually less than one order of magnitude greater than levels in the control organisms even after one month of exposure. Although some sediments exhibited high levels of some metals, it is invalid to compare metal levels in organisms to total sediment chemical concentrations since only a variable and small amount of the sediment-associated metal is available for biological uptake. In addition to not knowing the amount of metal available for biological uptake, animals in undisturbed environments may naturally have high and fluctuating metal levels. Therefore, comparisons should be made between control and experimental organisms at the same point in time in order to evaluate bioaccumulation.

Of a total of 168 animal-sediment-salinity combinations evaluated in tests carried out by Neff et al., only 22 percent showed significant accumulation due to sediment exposure. The largest uptake was of iron, a metal generally known for its low degree of toxicity in biological systems. Significant accumulations of lead were seen in a few of the short-term exposures, although these could not be duplicated in long-term exposures. Relatively high uptake of lead occurred only in the polychaete Neanthes and was interpreted to be potentially ecologically significant for this species. Their literature search showed that heavy metals in solution vary over several orders of magnitude in availability to benthic invertebrates. Although accumulation of heavy metals by organisms from the water has been documented, the literature shows no such clear evidence for accumulation of metals from the sediments.

Neff et al. also investigated the depuration of heavy metals after the organisms were removed from the test sediments. In those 37 cases where there was uptake after eight-day exposure, depuration during two or eight days in clean water was seen in seven instances, with the other 30 cases showing no decrease in metal concentration in the tissues.

In a field investigation of the San Francisco Bay system, Anderlini et al. looked at nine toxic metals (silver, arsenic, cadmium, copper, mercury, nickel, lead, selenium, and zinc) and five invertebrates (Ampelisca milleri, Macoma balthica, Neanthes succinea, Mytilus edulis, and Ischadium demissum).[30] Metal concentrations in sediments and organisms fluctuated within and outside the impact zone during the period of the study. Changes in the mean metal concentrations in sediments and all invertebrates during the study period were relatively small, considerably less than one order of magnitude. Mean metal concentrations in sediments and benthic invertebrates changed by less than a factor of two, and changes in metal levels in Mytilis edulis were no greater than a factor of three. These changes could not be directly attributed to dredging activities. Metal concentrations were similar in Mytilis edulis that were transplanted from clean water to stations within and outside the impact zone. Mussels transplanted to contaminated bay stations appeared to accumulate copper, nickel, and zinc over controls kept in clean water coastal stations

but to a lesser extent than native mussels. Desorption of metal species by mussels 27 days after being transferred from bay or ocean stations occurred in the following order of decreasing depuration: zinc, mercury, copper, lead, nickel, cadmium, and arsenic. Selenium was not depurated from mussel tissue in 27 days.

The accumulation potential of a metal may be affected by several factors such as depuration, exposure, salinity, water hardness, exposure concentration, temperature, and the particular organism under study. The relative importance of these factors varies from metal to metal. Data of Neff et al. on salinity effects were inconclusive, but there was a trend toward increased uptake at lower salinities.[29] Anderlini et al. exposed Macoma balthica to the chloride salts of various metals in the water column in a nine-day laboratory study.[30] Their data supported field observations in which Macoma balthica showed the highest metal concentrations following dredging periods when heavy rains resulted in a marked decrease in salinity.

The study by Neff et al. indicates that the chemical form of metals had important effects on their bioavailability. Elevated concentrations of heavy metals in tissues of benthic invertebrates were not always indicative of high levels of metals in the ambient medium or associated sediments. Although a few instances of uptake were seen to be of possible ecological significance, diversity of results among species, different metals, types of exposure, and salinity regimes strongly argued that bulk chemical analysis of sediments for metal content could not be used as a reliable index of metal availability and potential ecological impact of dredged material. Their work indicated that a biological assessment was necessary.

Neff et al. performed sequential and nonsequential chemical extractions on the sediments to evaluate the potential mobility of metals in different chemical forms. They also determined the total metal concentration in the sediment. For some species a correlation did exist and for others a correlation did not exist between any chemical or physical form studied and bioaccumulation of the metal. These authors stated:

> At present, it does not appear that a simple extraction scheme can be developed that might indicate availability of sediment sorbed metals by benthic organisms. Additional data, based upon a large number of different sediment types, may indicate, however, forms most likely to be accumulated by benthic organisms.[29]

For some metals there was apparent correlation between metal concentration in the sediment and in the associated infaunal and epifaunal macrobiota. For other metals no such correlation existed.

These correlations often vary with sediment type. The correlation, when it occurs, may be due to direct or indirect transfer of metals from sediment to biota or it may represent the presence of a common source of metals to both the sediment and biota. Anderlini et al. concluded that if changes in metals in the water occurred as a result of dredging activities, the changes were either less than small natural fluctuations or were of short duration.[30]

Both Neff et al. (short-term laboratory studies and literature review[29]) and Anderlini et al. (longer term field work and backup laboratory experiments[30]) found the same heavy metal phenomena. The accumulation and release of certain heavy metals seems to vary with the metal, with the species, between sampling times, between sampling sites (dredged and not dredged), and within control sites or organisims or both. These variable results have not been directly correlated with dredging operations or sediment loading.

A recent field study supporting the laboratory results of Neff et al. has been carried out by Simms and Presley.[31] These authors concluded that mollusks, crustaceans, and bony fishes from a dredged area of San Antonio Bay, Texas, were lower in almost every heavy metal than were organisms from other areas where dredging was minimal. Mollusks were observed to concentrate metals more than any other organisms studied, but the levels observed were much lower than those thought to be lethal or toxic. Except for a few large fish, metal concentrations did not correlate significantly with size or growth stage. Vigorous shell dredging in the bay for 50 years apparently did not cause increases of heavy metals in the tissues of local biota.

Studies[21] were conducted using harbor sediments chosen for physical similarity to bentonite suspensions used in previous turbidity studies,[22] in order to assay for impacts due to chemical properties of the sediments in suspension. Measurements were carried out using sediments from relatively uncontaminated reaches of San Francisco Bay and compared with measurements on more highly contaminated bay sediments. Organism response did not differ greatly between pure mineral suspensions[22] and uncontaminated natural sediments.[21] In many cases, lethal effects were more marked with the contaminated sediments.[21] Sediment characteristics are presented in Table 3. The most sensitive species tested, striped bass (*Morone saxatilis*) survived only a few hours at levels of 0.5 grams per liter of contaminated sediments, a condition probably representing a worst-case of turbidity generation associated with a dredged material disposal operation. Such conditions are very unlikely to occur in the field, where motile organisms may escape turbidity maxima and where water currents disperse sediments as they settle out of the water column.

Chemical analyses of several species of heavy metals, pesticides, and polychlorinated biphenyls (PCB's), presented in Tables 4-7, indicate minimal uptake of some of the contaminants, but none were

Table 3

Chemical Characterization of Contaminated Sediment Used in the Estuarine and Marine Tests[21]

Parameter	Sediment Fraction: Total mg/kg	Exchangeable mg/kg	Interstitial Water, mg/ℓ	Elutriate mg/ℓ
% water	48.3	--	--	--
pH	7.8	--	--	--
Eh	-414	--	--	--
Total Sulfides	6148	--	--	--
Total Phosphates	878	--	--	--
Orthophosphate	--	--	2.3	1.4
Total Kjeldehl Nitrogen	0.15%	--	--	--
Ammonium	--	88.8	--	(3.49)
Arsenic	128	0.50	0.12	0.14
Cadmium	2.3	1.09	0.16	(0.14)
Copper	158	1.6	0.10	0.06
Iron	3.62%	--	2.5	0.18
Manganese	333	114	5.1	0.49
Mercury	1.47	0.55	0.15	(0.16)
Nickel	104	62.4	6.4	9.6
Selenium	1.49	0.62	0.48	0.46
Zinc	381	4.0	0.12	0.04
Total PCB's	1.30	--	--	--
Total DDT	0.750	--	--	--

Table 4

Contaminant Concentrations in the Tissue of the Mussel *Mytilus edulis* in the Chemical Uptake Study in the Contaminated Sediment Phase of the Estuarine Test[21]

Suspended Solids g/ℓ	Exposure days	Metal-Content, μg/g wet								
		Arsenic	Cadmium	Copper	Iron	Lead	Manganese	Mercury	Nickel	Zinc
At collection		0.09	0.96	2.05	71	0.19	2.71	0.15	0.68	38.4
0	3	0.15	0.09	5.98	176	0.15	7.74	0.12	1.24	45.6
0	10	0.15	0.32	1.74	131	0.19	3.29	0.05	0.94	25.0
0	15	0.28	0.26	1.16	100	0.23	1.16	0.02	1.74	20.2
0	21	0.6	0.44	1.14	95	0.18	3.09	0.06	2.60	39.1
0	P	0.06	0.28	0.85	49	0.15	3.49	0.02	3.15	27.5
3.6	P	0.16	2.15	5.22	154	1.68	2.99	*	2.72	100.0
12.1	P	0.10	1.16	2.43	55	0.34	2.92	*	1.46	55.9
15.9	P	0.08	1.07	2.83	58	0.18	1.95	0.11	1.17	50.0

P = Animals were exposed to indicated suspended solids concentration for 21 days then placed in clear water 5 days to purge the sediment from the digestive tract and body surfaces before analysis.

Table 5

Whole Body Concentrations of Selected Metals in Chemical Uptake Study with Contaminated Sediment in the Marine Test[21]

Species	Suspended Solids Exposure	Metal-Content, µg/g wet								
		Arsenic	Cadmium	Copper	Iron	Lead	Manganese	Mercury	Nickel	Zinc
Mytilus edulis	Control	0.12	0.34	2.48	154.0	2.14	2.53	0.63	0.04	25.7
	Purged	0.20	0.10	7.66	215.0	3.89	2.48	0.02	0.05	33.6
Mytilus californianus	Control	0.17	0.51	3.52	162.0	0.97	1.62	0.21	0.08	22.7
	Purged	0.12	0.45	9.23	88.8	2.28	0.95	0.03	0.004	25.0
Crangon nigromaculata	Control	0.03	0.06	4.95	38.8	0.55	0.87	0.13	0.01	7.2
	Purged	0.08	0.23	9.08	25.6	0.27	8.20	0.14	0.52	22.7
Cancer magister	Control	0.03	0.10	16.8	55.9	0.31	1.00	*	0.19	13.3
	Purged	0.03	0.13	13.2	51.4	0.38	8.06	*	0.37	16.8

* = Insufficient sample for analysis.

Table 6

Contaminant Concentrations in the Tissue of the Mussel *Mytilus edulis*

in the Chemical Uptake Study in the Contaminanted Sediment

Phase of the Estuarine Test[21]

Suspended Solids g/ℓ	Exposure days	Chlorinated Hydrocarbons-Content, μg/g wet							
		DDE	DDD	DDT	Total DDT	Aroclor 1241	Aroclor 1254	Aroclor 1260	Total PCB's
At collection		0.68	0.32	-	1.00	0.02	0.05	0.01	0.08
0	3	1.18	0.38	-	1.56	0.02	0.06	0.01	0.09
0	10	0.52	0.84	-	1.36	0.02	0.03	0.01	0.06
0	15	0.50	0.46	-	0.96	0.02	0.06	0.02	0.10
0	21	0.18	0.85	-	1.03	0.04	0.02	0.01	0.07
0	P	0.55	0.40	-	0.95	0.06	0.02	0.01	0.09
3.6	P	0.75	0.83	-	1.58	0.07	0.07	0.02	0.16
12.1	P	0.49	1.10	-	1.59	0.05	0.03	0.02	0.10
15.9	P	0.47	0.68	-	1.15	0.05	0.02	0.01	0.08

P - Animals were exposed to indicated suspended solids concentration for 21 days then placed in clear water 5 days to purge the sediment from the digestive tract and body surfaces before analyses.

Table 7

Whole Body Concentrations of Selected Chlorinated Hydrocarbons

in Chemical Uptake Studies with Contaminated Sediment

in the Marine Test[21]

Species	Suspended Solids Exposure	Chlorinated Hydrocarbons-Content, μg/g			
		DDE	DDD	DDT	Total DDT
Mytilus edulis	Control	1.71	-	0.69	2.40
	Purged	2.02	-	-	2.02
Mytilus californianus	Control	1.66	-	-	1.66
	Purged	2.57	-	-	2.57
Crangon nigromaculata	Control	1.54	-	-	1.54
	Purged	1.39	-	-	1.39
Cancer magister	Control	0.14	-	-	0.14
	Purged	0.14	-	-	0.14

- = Below detection limits; DDD 0.006 ng/g; DDT 0.008 ng/g. Also below detection limits were aldren, dieldrin, heptachlor 0.004 ng/g; chlordane 0.008 ng/g; endrin, PCB's 0.1 ng/g.

accumulated to levels which appeared to be sufficient to influence the survival of the exposed organisms.[21] Moreover, body burdens or tissue levels did not exceed those levels generally considered acceptable for edible portions for human consumption. Difficulties in interpreting such chemical data, however, argued for developing assay techniques to evaluate total toxicity of a sediment regardless of specific toxicants. There were analytical difficulties in this study that limit comparison to relative differences among treatment rather than allow an absolute comparison.

The term "oil and grease" is used in describing collectively all petroleum hydrocarbon components in sediments of natural and contaminant origin which are primarily fat soluble. A literature review demonstrated a broad variety of possible oil and grease components in sediment, the recovery of which was dependent on the type of solvent and methodology used to extract these residues.[32] Trace contaminants, such as the PCB's and chlorinated hydrocarbons (DDT and derivatives), often occur in the oil and grease. Large amounts of contaminant oil and grease find their way into the sediments of industrialized waterways either by spillage or as chronic inputs in municipal and industrial effluents, particularly near urban areas with major waste outfalls. The literature suggested long-term retention of oil and grease residues in sediments with minor biodegradation occurring. Where oily residues of known toxicity became associated with sediments, these sediments retained toxic properties over periods of years, affecting local biota. Spilled oils are readily adsorbed to naturally occurring suspended particulates, and oily residues from municipal and industrial effluents are commonly found adsorbed to particles. These particulates are deposited in benthic sediments and are subject to resuspension during disposal.

Using the elutriate test, DiSalvo et al. showed some release into the water of soluble hydrocarbon residues from sediments known to contain 2,000 to 6,000 ppm total hydrocarbons.[32] Hydrocarbon concentrations in the elutriate (100 to 400 ppb) were from 11 to 400 times higher than background concentrations, yet were well below acceptable effluent discharge standards. The amount of oil released during the elutriate test was less than 0.01 percent of the sediment associated hydrocarbons under worst-case conditions.[32]

A test scheme was employed in which estuarine crabs (<u>Hemigrapsus oregonensis</u>), mussels (<u>Mytilus edulis</u>), and snails (<u>Acanthina spirata</u>) and a freshwater clam (<u>Corbicula sp.</u>) were exposed to contaminated sediments in order to determine magnitudes of uptake of hydrocarbons that were included in sedimentary oil and grease burdens. Sediments characteristics are shown in Table 8.

There was no overt mortality of test organisms that was directly attributable to exposure to contaminated sediments. Experimental evidence as presented in Table 9 suggested slight uptake of hydrocarbons by saltwater test organisms incubated in the presence of

Table 8

Characteristics of Sediments Used for DiSalvo Study[32]

Sample	Dry Solids % Sediment	Volatile Residue % Dry Solids	Oil and Grease % Dry Solids	Hydrocarbons % Oil and Grease
Duwamish River (Slip 1)	49.0	7.1	0.12	52
Duwamish River	36.6	6.4	0.23	37
Oakland Middle Harbor	51.6	7.8	0.07	62
New York Harbor (Bay Ridge)	30.1	10.2	0.88	68
New York Harbor (Perth Amboy)	34.4	13.0	0.45	63

	Concentrations, µg/g dry weight				
Sample	Oil and Grease (A)	Total Hydrocarbons (B)	Hydrocarbons Desulfurized (C)	Sulfur (B-C)	Polar Materials (A-B)
Duwamish River (Slip 1)	1224	637	338	299	587
Duwamish River	2301	854	413	441	1447
Oakland Middle Harbor	748	462	275	187	286
Oakland Middle Harbor (aged)	1050	710	93	617	340
New York Harbor (Bay Ridge)	8755	5930	4145	1785	2825
New York Harbor (Perth Amboy)	4525	2850	1580	1270	1675

Table 9

Hydrocarbon Analyses by TLC* of Organisms Exposed to Duwamish River Dredged Material[32]

Organism	Tank Series**	Time Days	Hydrocarbon Content µg/g Dry Tissue (ppm) Alkanes	Arenes	Total
Crab (*Hemigrapsue oregonensis*)		0	14	2	16
	SED	17	22	7	29
	SED (Ref)	17	8	3	11
	SCR	17	21	14	35
	SCR (Ref)	17	19	10	29
	STR	17	25	6	30
	STR (Ref)	17	10	5	15
Mussel (*Mytilus edulis*)		0	143	35	178
	SED	30	35	58	93
	SED (Ref)	30	48	47	97
	SCR	30	84	54	138
	SCR (Ref)	30	35	6.5	41.7
	STR	30	110	52	162
	STR (Ref)	30	63	15	78
Snail (*Arcanthina spirata*)		0	6	4	9
	SED	30	14	7	21
	SED (Ref)	30	4	4	8
	SCR	30		-†	
	SCR (Ref)	30	6	2	8
	STR	30	28	37	65
	STR (Ref)	30		-†	

* Thin-layer chromatography

** Entries in this column are defined as follows:
SED - organisms in sediment
SCR - organisms on screen 5 cm above sediment
STR - organisms on screen 30 cm above stirred sediment
(Ref) - reference sediment

† Contaminated

Duwamish River sediments, which contained almost 500 ppm total hydrocarbons.[32] Freshwater clams exposed for 30 days to Duwamish River sediments showed no well-defined uptake of hydrocarbons. As shown in Table 10, mussels and crabs exposed for four days to New York Harbor sediments containing 2,000 ppm total hydrocarbons showed average uptakes above background of about 50 to 70 ppm (2.5 and 3.5 percent, respectively, of the sedimentary hydrocarbon concentration).[32]

The results indicate that selected estuarine and freshwater organisms can be exposed for periods up to 30 days to dredged material that is contaminated with thousands of parts per million oil and grease and experience minor mortality. Uptake of hydrocarbons from the heavily contaminated sediments appears minor when compared to the hydrocarbon content of the test sediments and when compared to results describing exposure of uncontaminated organisms under field conditions where total hydrocarbon uptake ranged to several hundred parts per million.[32, 33]

Attempts have been made to trace pathways of uptake of sediment-associated DDT into the tissues of estuarine deposit-feeding benthic infauna.[34] The data obtained suggest the possibility of uptake of DDT under model laboratory conditions that may or may not be operative under field conditions. Fulk et al. reviewed the literature on pesticides and PCB's in sediments, algae, suspended solids, bottom sediments, and water containing various chlorinated hydrocarbons.[14] The studies that they reviewed reported results of tests conducted to determine the adsorption and desorption of chlorinated hydrocarbons on solids and generally indicated that the materials were much more readily sorbed than desorbed. Fulk et al. analyzed the sediments from five locations for aldrin, dieldrin, endrin, lindane, 2,4-D esters, DDT analogs, toxaphene, and PCB's and found that PCB's, dieldrin, and the DDT analogs were the most prevalent. The desorption characteristics of the DDT analogs and dieldrin were studied. No release of DDT residues was observed. Some dieldrin release was observed in the parts per trillion range. On the basis of these laboratory studies, it appears that release of these water-insoluble pesticides will not occur to an appreciable extent during disposal. During a disposal operation in San Francisco Bay, Anderlini et al. monitored release of PCB's and compounds of the DDT group from sediments and subsequent uptake by organisms.[35] Some uptake of p,p-DDE was observed, but the levels of the other chlorinated hydrocarbons remained constant in *Mytilus edulis*.

Field Investigations

The short- and long-term chemical, physical, and biological impacts of open-water disposal have been determined by large-scale field investigations in numerous locations.[25] Chemical water-column

Table 10
Hydrocarbon Analyses by TLC* of Organisms
Exposed to Two New York Harbor Dredged Materials[32]

Source Dredged Material	Organism	Time Days	Tank Series**	Hydrocarbon Content µg/g Dry Tissue (ppm) Alkanes	Arenes	Total
New York Harbor (Perth Ambov)	Crab (*Hemigrapsus oregonensis*)	0		19	6	25
		0		21	7	28
		4	STR #1	47	21	68
		4	STR #1	59	34	93
		4	STR #2	66	42	108
		4	STR #2	83	35	120
	Mussel (*Mytilus edulis*)	0		17	46	63
		4	STR #1	22	65	87
		4	STR #1	28	76	104
		4	STR #2	18	86	104
		4	STR #2	20	143	163
New York Harbor (Bay Ridge)	Crab (*Hemigrapsus oregonensis*)	0		62	11	73
		1	SED	58	22	80
		1	SCR	24	5.2	30
		1	STR	70	22	92
	Mussel (*Mytilus edulis*)	0		25	22	46
		27	SED	72	121	193
		27	SCR	23	32	55
		27	SCR	108	180	288

* Thin-layer chromatography
** Entries in this column are defined as follows:
SED - organisms in sediment
SCR - organisms on screen 5 cm above sediment
STR - organisms on screen 30 cm above stirred sediment

effects duplicated the laboratory results previously reported in this paper, where only low levels of some nutrients and the metals iron and manganese were apparently released. Analyses of the sediment at the sites showed initial elevated concentrations of chemical constituents in the sediment interstitial water at the disposal site, but with time the concentrations were similar to those in the reference areas. Movement or release of these chemical constituents out of the sediments of the disposal or reference sites was not apparent. Turbidity or suspended particulate was found in concentrations significantly lower (an order of magnitude or more) than concentrations shown to have an impact on a broad range of aquatic organisms and persisted only for a few hours.[21, 22, 23, 24, 26] A significant impact noted in these studies was the mounding of dredged material on the bottom of the dump sites.[25] Biological recolonization studies of these mounds showed that conditions returned to a predump status; there was rapid biological recolonization of the fine-grained disposal areas while sandy substrates exhibited slower recovery.

DMRP studies were conducted where organisms at select sites were analyzed for metals or chlorinated hydrocarbon uptake.[25,36,37,38,39] Evidence from freshwater, estuarine, and marine sites showed no increased uptake of numerous toxic and nontoxic metals and chlorinated hydrocarbons by several organisms when compared with control or reference areas.

Freshwater site. The aquatic disposal field investigation site at Ashtabula, Ohio, was located in Lake Erie just north of the entrance to Ashtabula Harbor (Figure 1).[36] The movement of surface water in the lake is counter-clockwise although reversals occur with northeast winds. A compensating current is found in the deeper waters of the lake during thermal stratification (June-October). Because of the configuration of the lake, any contaminants released along the south shore tend to move eastward along the shore. Oxygen depletion occurs in the deeper water during the summer.

Sediment in the disposal area primarily originates from material transported by the longshore current and, to a lesser extent, from the Ashtabula River, which enters Lake Erie through Ashtabula Harbor. The sediment consists of about equal parts of sand and silt with a small amount (not more than 10 percent) of clay. There is apparently little variation in grain size with depth.

Although there have been severe water quality problems in the lake, striking improvements have been noted in recent years. At the Ashtabula aquatic disposal field investigation site, water quality variables tended to be quite uniform throughout the water column except during thermal stratification. The expected differences resulting from stratification were observed; during periods of upwelling, deeper (hypolimnetic) water was often found quite near the surface.

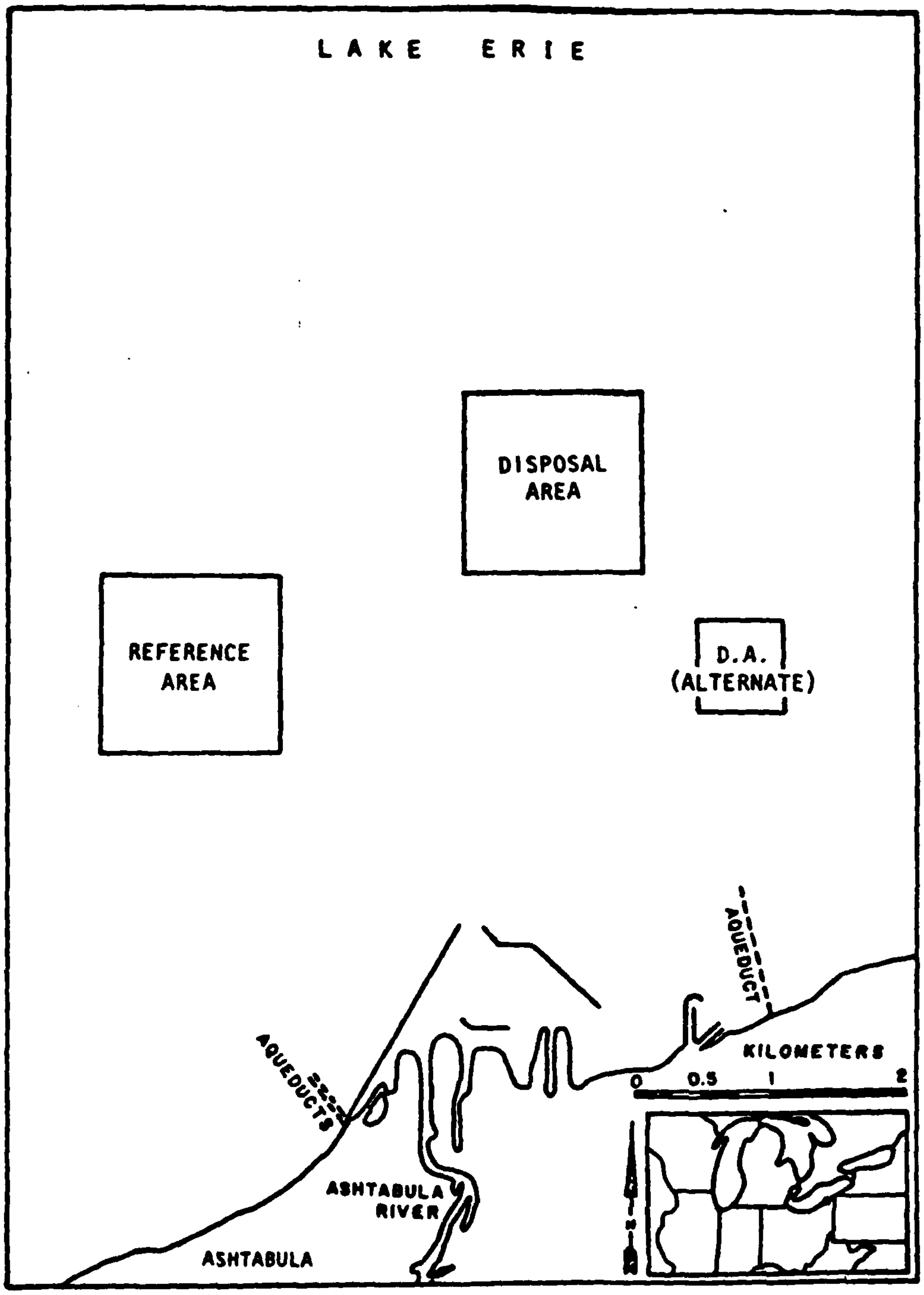

Figure 1. Location of Disposal and Reference Areas, Ashtabula Disposal Site, Ohio

A variety of invertebrates and fish inhabit the area. The former includes mollusks, worms, insect larvae, and crustaceans. These form a food supply for the 40-odd species of fish that were observed. Yellow perch were the most abundant species, with alewife, gizzard shad, and white sucker being quite common. Moderate to abundant populations of both zooplankton and phytoplankton occur throughout the lake.

The Ashtabula area is heavily industrialized and is a major port facility. There are a number of industrial and agricultural sources of contaminants in the immediate vicinity, and there are two fossil-fuel power-generating stations east of Ashtabula.

Open-water disposal in a designated area by hopper dredges resulted in the formation of mounds of dredged material. There were numerous small mounds 30 to 50 cm high, rather than a single mound. Disposal operations created a small (less than 2°C) transient increase in temperature in the water column; disposal during thermal stratification did not alter the thermal structure. There was little change in sediment grain size after disposal, and those few changes observed disappeared within three months. Erosion of the mounds occurred as a result of fall and winter storms, and there was a net transport of material to the northwest and southeast.

Almost all of the chemical variables measured in the water column were affected by disposal.[36] Effects were not great, however, and the minor increases in chemical variables were limited to the proximity of the dredge. An essentially complete return to ambient predisposal conditions by most variables was noted within a few minutes. Water quality was not impaired. The overall impact of disposal is not entirely clear as some constituents increased, presumably through release, while others decreased probably resulted from sorption onto settling dredged material. The impacts, however, were nearfield and short lived.

There were changes in disposed sediment interstitial water chemistry after disposal.[36] A return to predisposal conditions took from 30 to 90 days. It should be kept in mind that the sediments were eroding and being compacted or reworked after disposal. This process in itself could bring about various changes in interstitial water chemistry.

The greatest chemical effect of disposal appears to have been observed in the sediment. Following disposal, nutrients increased in the sediment, but metals (except mercury) decreased. This effect is not surprising as it reflects the relative concentrations of nutrients in lake sediments and harbor sediments and the natural background levels of metals.

Overall interpretation of the results of sediment chemistry is difficult because of the behavior of dredged material when released and because of the characteristics of natural lake sediments. Rather than there being an overlay of dredged material upon natural lake bottom, the physical impact of the dredged material striking the bottom resulted in bottom currents. These currents pushed lake-bottom sediments to the periphery of the study area and on top of previously deposited dredged material. Hence, alternating series of dredged material and natural bottom resulted, with subsequent compaction and reworking serving to further obscure measurable differences between the two sediment types.

Disposal operations at Ashtabula had essentially no measurable impact upon planktonic organisms.[36] Benthic organisms were affected in several ways. There was no change in the number of species present in the disposal area immediately following disposal, but there were a number of changes in species composition, with new species transported from the harbor replacing those that had been eliminated. In addition, there was a large increase in the number of organisms in the disposal area. Many of the changes appeared to be initially confined to the immediate area of disposal. As erosion spread the dredged material over a larger area, faunal changes in the expanded area were observed. Of interest was the finding that enumeration of gross animal groups (such as the family level of identification) was not adequate to determine impacts; rather, an examination at the species level was required.

Adult and young pelagic fish did not appear to be impacted by disposal. However, bottom-dwelling fish showed a negative response to disposal by migrating from the area. Within an hour after disposal, these fish had returned to the disposal area. Overall, the effects of disposal upon fish were of small magnitude and persisted only for a short period of time.

Metal concentrations in fish and invertebrates, presented in Tables 11 and 12, showed few changes resulting from disposal. The relative concentration of metals in fish were the same as those observed in the sediment, whereas a decrease was noted in some of the invertebrates. Hence, bioaccumulation apparently did not occur.

Additional freshwater field investigations were conducted at 32 designated open-water disposal sites in the Great Lakes from May, 1978, to June, 1980.[40] The investigators concluded that there was no readily apparent long-term universal consequence of open-water disposal of the dredged material. Chemically, there was no difference between the reference and disposal areas at 75 percent of the sites. Biological data indicated stressed populations at 28 percent of the disposal sites and 25 percent of the reference sites.

Table 11

Overall Statistics for Mean weight and Metal Concentrations in Fish Groups[36]

	Weight, g and Metal Concentrations, μg/g dry				
	Reference Area Pre-75	Disposal Area Pre-75	Reference Area Post-75	Disposal Area Post-75	1 mi N CEI Area Post-75
Weight	165.7	80.3	55.0	153.8	270.0
Mercury	0.51	0.18	0.25	0.38	0.31
Iron	171	110	46	197	181
Lead	9.3	2.5	1.7	5.3	5.5
Cadmium	5.9	0.7	0.6	1.7	0.9
Chromium	0.6	0.3	1.1	1.1	0.8
Nickel	4.2	1.6	2.5	3.8	3.8
Copper	3.6	4.0	3.2	5.8	3.5
Manganese	15.1	11.6	10.2	17.8	10.5

Table 12

Comparison of Metal Concentrations in Oligochaetes by Area[36]

	Concentrations, μg/g wet				
Metal	Reference Site All Cruises	Disposal Sites May (predis-posal)	River Sites May (predis-posal)	Disposal Sites June (5-days post)	Disposal Sites July (30-days post)
Cadmium	0.72	0.19	0.03	0.13	0.13
Copper	11.0	11.6	3.0	3.7	2.7
Manganese	18.9	11.1	7.9	7.5	9.1
Zinc	152	54.6	21.0	57.2	27.4
Iron	1385	952	450	696	587

Estuarine site. The Duwamish River enters Elliott Bay, a part of Puget Sound (Figure 2).[38] The entire river is tidal with horizontal and vertical variations in salinity levels. These levels depend upon tidal stage and river discharge. Low dissolved oxygen concentrations (less than 3 mg/liter) occur near the bottom of the river. Although quite important as a waterway, the Duwamish is also a major migration route for salmon and trout.

Elliott Bay is a rather typical estuarine system with surface water of low salinity over a deeper layer of more saline water. During the summer, density stratification is present, but in the winter colder fresh water from the waterway entrains and mixes with warmer saline water. Hence, there is usually no stratification in the winter. Because it is an estuary, water column chemical constituents tend to be rather variable. The waterway has created an underwater delta along the south side of the bay. The deltaic sediments consist mainly of silty sand mixed with wood and other organic debris. The dominant demersal fish in the bay during the winter are assorted soles, and the dominant benthic invertebrate is the pink shrimp. Worms and various mollusks are also important components of the bottom fauna.[38]

In the past, the Duwamish was dredged with a hydraulic pipeline dredge and upland disposal was used. However, the increasing cost of land for upland disposal and a scarcity of sites required a shift to the use of mechanical dredging and open-water disposal with barges. In 1974, there was a spill of almost 1,000 liters of PCB's at Slip 1, resulting in serious PCB contamination in the maintenance-dredging area of the river. The most highly contaminated sediments were hydraulically dredged and placed in an impervious containment area. The remaining less-contaminated sediments were removed by a clamshell dredge, placed in barges, and transported to an experimental open-water disposal site. The dredging and upland containment of the highly contaminated sediments were carefully monitoring by the Environmental Protection Agency (EPA). The EPA found that there was a minimal release of metals, nutrients, and hydrocarbons in the dredging area.[41]

The material dredged from the Duwamish Waterway was an oily, black, fine organic silt with a plastic texture.[38] It was found to leave the disposal barge in clumps or as a well-defined mass and fall to the bottom with velocities of up to 180 cm/sec. Upon impact with the bottom, a dense surge of material flared outward at about 36 cm/sec and could be detected more than 200 meters from the point of impact. Suspended solids returned to ambient conditions within 10 minutes, but a slight reduction in light transmittance persisted for several hours.[38]

The disposal of 114,000 m^3 resulted in numerous mounds two to three meters in height with a maximum radius of approximately 200 meters. Subsequent chemical analysis for PCB's at six and nine months

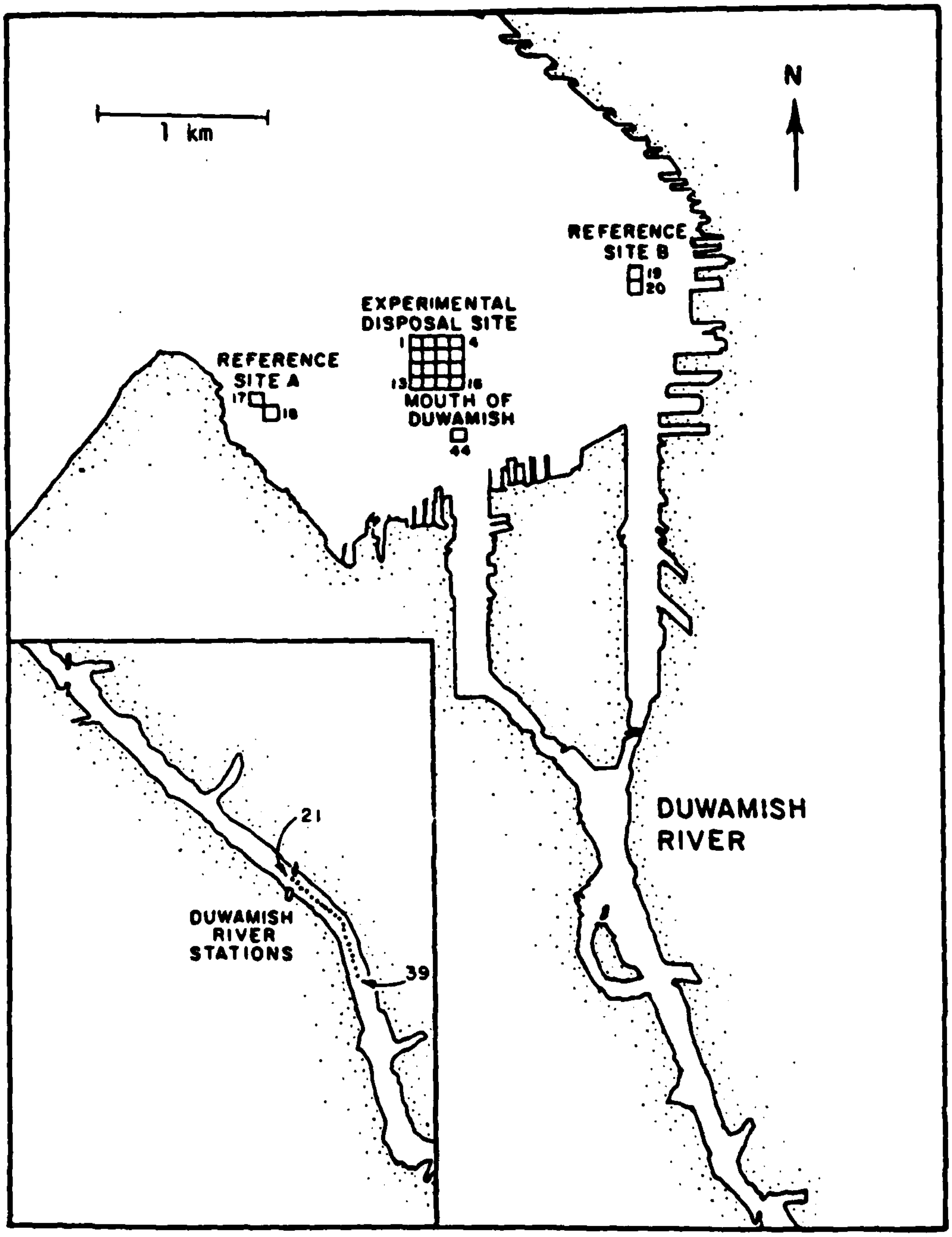

Figure 2. Locations of Duwamish Waterway Disposal and Reference Sites, Puget Sound, Washington (38)

after disposal indicated that the mound was gradually spreading.[38] This movement was probably brought about by currents gradually redistributing the dredged material. The spreading was not of sufficient magnitude to move the contaminated sediments beyond the boundaries of the disposal site.

The majority of chemical changes in the water column during disposal were relatively minor.[38] There were increases in dissolved manganese, ammonia, phosphorous, and total PCB's. These changes occurred with increases in suspended particulate matter; when the particulate matter decreased, so did the concentrations of contaminants. The increase in particulate matter and associated chemical variables was of extremely short duration, usually less than 30 minutes. It is of interest that, prior to disposal, the concentration of PCB's in the water column exceeded EPA criteria and that this concentration increased after disposal. It is possible that PCB's were entering Elliott Bay from the Duwamish Waterway and had approached equilibrium saturation values prior to disposal.

As would be expected, the chemical changes observed in the sediment are a reflection of the nature of the dredged material.[38] Metals, nutrients, PCB's, and oil and grease were present in the disposal area sediment in greater concentrations after disposal than before disposal and reflected those concentrations found in the dredging site.

A number of biological variables were investigated during the Duwamish aquatic disposal field investigation, and a few showed major changes as a result of disposal. The number of species, density, biomass, and diversity of benthic invertebrates at the disposal site were depressed after disposal (when compared to values taken before disposal).[38] These effects were more apparent for the central stations of the disposal site and least noticeable for the corner stations. Some decreases in the above parameters were also noted for the two reference stations. Nine months after disposal, the number of species present at the disposal site was comparable to the numbers present at the two reference sites although the biomass values continued to be depressed for the central and side stations of the disposal site. There was evidence that animals at the edges of the disposal site were stimulated by the dredged material.

As presented in Tables 13 and 14, there was essentially no uptake of metals or PCB's by fish or most invertebrates analyzed during and after the disposal operations. Specimens taken before and after disposal were collected from the disposal site and locations outside Elliott Bay. In addition, caged animals were held at the disposal site for up to three weeks. Mussels held in cages at the disposal site accumulated PCB's to levels slightly above background levels, but the increase was not statistically significant. It should be pointed

Table 13

Mercury and Chromium Concentrations in Organisms from Duwamish Waterway Study[38]

Organism	Exposure weeks	Sample	Mercury, ppm Disposal Site	Mercury, ppm West Reference	Chromium, ppm Disposal Site	Chromium, ppm West Reference
Sea Cucumber						
Predisposal	0	$\bar{X}$	0.01	0.01	0.32	0.32
Postdisposal	1	$\bar{X}$	0.01	0.01	0.26	0.24
	2	$\bar{X}$	0.01	0.01	0.26	0.24
	3	$\bar{X}$	0.01	0.01	0.26	0.24
Spot Shrimp						
Predisposal	0	$\bar{X}$	0.06	0.06	0.64	0.64
During Disposal	3	$\bar{X}$	0.06	--	0.62	--
	3	$\bar{X}$	0.06	--	0.61	--
	7	$\bar{X}$	--	0.07	--	0.57
Alaska Pink Shrimp						
Predisposal	0	$\bar{X}$	0.08	0.06	0.83	0.63
Postdisposal	2	$\bar{X}$	0.06	0.06	0.68	0.62
	5	$\bar{X}$	0.07	--	0.63	--
	14	$\bar{X}$	0.05	0.06	0.55	0.67
	27	$\bar{X}$	0.04	0.05	0.50	0.58
	39	$\bar{X}$	0.04	0.05	0.62	0.70

Table 14

PCB Concentrations in Organisms from Duwamish Waterway Study[38]

Organism	Location	Exposure Time Weeks	Mean PCB Content, ppm
Mussel (Mytilus edulis) exposed after disposal		0	0.122
	West Reference Site	1	0.103
		2	0.131
		3	0.100
	Disposal Site	1	0.108
		2	0.200
		3	0.206
Spot Shrimp (Pandalus platyceros)		0	0.174
exposed during disposal	West Reference Site	7	0.190
	Disposal Site	3	0.208
		3	0.185
English Sole (Parophyrys vetulus) exposed after disposal	West Reference Site	0	2.28
		2	0.65
		4	0.87
		36	5.90*
	Disposal Site	0	2.58
		2	0.74

* One sample only.

out, however, that some of the animals collected from Elliott Bay prior to disposal contained substantial amounts of PCB's so a slight uptake may not have been statistically significant.

Demersal fish and shellfish (shrimp) seemed to ignore disposal operations. Fewer were present during disposal at the disposal site than at the east reference site, but it was about the same number as at the west reference site. After disposal the number of fish decreased at the disposal site and at both reference sites; this decrease suggests a seasonal change in these organisms rather than an impact of disposal.[38] The number of shrimp captured at the disposal site after disposal increased compared to those obtained prior to disposal. Shrimp at the reference sites either remained at the same level (east reference site) or increased erratically from month to month (west reference site). Overall, more shrimp were found at the disposal site after disposal than at either reference site, indicating that the shrimp were attracted to the disposal site. Two additional years of study at this estuarine site have verified initial findings, especially with respect to PCB concentrations.

Upland Disposal

Containment of highly contaminated or toxic dredged material as a conventional alternative has been extensively investigated.[2, 3,] Confining contaminated material on land or in shallow water next to land can be an environmentally sound and preferred alternative, but cannot be categorically considered better than open-water disposal for several reasons and could be less effective in protecting water quality or organisms. These reasons include the changes in the geochemical environment that could lead to an enhanced release of contaminants and the risk inherent in retaining the fine-grained and colloidal particles and soluble fractions in environmental settings where they are likely to have greater impact when released (e.g., wetlands, small streams, and groundwater aquifers). Also, it should not be overlooked that confined facilities are expensive, of finite life, and result in a permanent change in the physical landscape, often in conflict with land-use and management plans.[3]

With time, the physicochemical environment of soil in a confined disposal site becomes appreciably different from that of sediments before dredging or sediment deposited in open water. The upland drained situation can lead to an oxidizing acidic environment that was shown in laboratory studies to be conducive to the leaching of contaminants, particularly heavy metals. Whether or not the leachate will contaminate groundwater will depend on the absorptive capacity of the underlying natural soil, proximity to aquifers, and groundwater hydrology. A far more serious and more probable impact can occur when saline sediments are placed in a freshwater upland environment. Salt

will leach from most dredged material, and whether or not it will contaminate ground water must be carefully evaluated on a case-by-case basis.

Composition of Dredged Material

Each year the nation's waterways, lakes, and harbors accumulate materials from a host of different sources. The composition of the sediment accumulated in waterways and harbors depends to a large extent on the source contributing the materials. One of the major contributing sources is runoff materials from land surfaces after rainfall. Rainfall detaches soil particles from the land and transports the soil particles and any materials that have sorbed to the soil particles, to streams, rivers, and lakes. Industrialization and increased population densities along navigable waterways have further altered the physical and chemical nature of many watersheds, resulting in the contamination of some river and harbor sediment. The following discussion on sediment characteristics in relation to land disposal can be found in more detail in references 42 and 43.

Texture. Dredged material is composed predominantly of soil particles ranging in size from coarse sand to fine clay. Dependent on geographical location, the material can have an extremely mixed mineralogy. Individual dredged material deposits can vary from a well-graded sand to a pure montmorillonitic clay. In addition to soil, dredged material can contain other solids, such as rock, wood, pieces of metal, broken glass, and other debris. Man's influences are also evident in sewage materials, elevated concentrations of heavy metals, and a vast array of chlorinated hydrocarbons, oil and grease, and other organics.

Organic materials. Dredged material varies widely in organic matter content. All CE districts have reported the presence of organic materials in maintenance dredging but, in most cases, not in excessively large quantities. Organic carbon concentrations as high as 10 percent are not uncommon, but comprise only a small volume of the materials dredged. Also included in the organic fraction of dredged material could be petroleum products, persistent organics, pesticides, and herbicides. The concentrations of petroleum products depends primarily on the extent of industrialization and the amount of traffic along the waterway.

Cation exchange capacity. The texture and organic matter content of sediments determine, to a large extent the capacity of that material to sorb and desorb cations, anions, oil and grease, and pesticides (e.g., fine silts and clays with relatively high amounts of plant nutrients as well as many other constituents). The cation exchange capacity (CEC) of a dredged material governs the sorption of ammonium nitrogen, potassium, and other cations, heavy metals, and some pesticides.

Nutrients. The nutrient content of dredged material varies widely, as does that of upland soils. Generally, finer textured dredged material contains considerably more nutrients than coarse-textured material. The predominant form of nitrogen in inorganic sediments is ammonium nitrogen. In organically enriched sediments, however, organic nitrogen predominates, although ammonium concentrations can be very high. Dredged material also contains varying amounts of soluble, exchangeable, and total potassium, calcium, and magnesium.

In most sediments, as in soils, phosphorus occurs as a phosphorus-solid complex. Studies have shown similar total phosphorus concentrations (450 to 3,600 ppm) in marine, estuarine, and freshwater sediments. However, ortho-phosphate concentrations as high as 80 ppm have been found in the interstitial water of these recent anaerobic sediments.

Sulfur. Concentrations of total sulfide in anaerobic dredged material have been found to range from 0 to 5,390 ppm in mineral sediments from marine, estuarine, and freshwater environments.[5, 12] Free sulfide concentrations of 200 ppm have been noted in some of the sediment samples. It has been reported that sediments in a South Carolina tidal marsh developed high acidity when drained and dried out. These sediments contained up to 5.5 percent total sulfur. When drained, sulfides were oxidized to sulfate with a resultant decrease in sediment pH from 6.4 to as low as 2.0. Similar sulfur acidity problems have been described for soils known as Katteklei (cat's clay) in Holland and along the east coast of the United States. "Cat's clay" effects may be a serious problem in dredged material containing high levels (usually greater than 0.1 percent) of nonvolatile sulfide, predominantly iron and manganese sulfide. This is especially true if the dredged material is not limed or counteracted by application to an alkaline upland soil.

Toxic metals. A wide range of toxic metal concentrations have been reported in a number of sediments from rivers, harbors, and bays throughout the United States and Canada. Some of the major sources of anthropogenic metals include industry and sewage discharges, urban and highway runoff waters, and snow removal. Wastes from metal-plating industries that have found their way into some sediments contain significant amounts of copper, chromium, zinc, nickel, and cadmium. Sediment chemical partitioning studies, however, have shown that these metals occupy the least stable of the sediment fractions and that the sediment physicochemistry dominates the mobility and availability of the contaminant as well as the indigenous metals.[5, 6]

The quantities of heavy metals discharged from industries that process or utilize heavy metals and from municipal sewage depend on the degree of pretreatment of discharged wastewaters. These quantities have been relatively large in the past. However, the Federal Water

Pollution Control Act Amendments of 1972 (Public Law 92-500) and the Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) require more complete pretreatment of wastewaters and should result in a reduction in the toxic metal and other contaminant contents of discharge wastewaters.[44]

Salt. Dredging, especially in coastal waters, results in material containing various amounts of salt, in some cases as much as three percent. Wastewaters also elevate the chloride content of inland harbor sediments. The salt content of dredged material should be reduced before land application or salinity problems may result. This approach, however, may require several years of leaching by rainfall after initial disposal in a holding basin.

Methods of Collection and Transport

Sediments are dredged from waterways and are conveyed to disposal areas either hydraulically or mechanically. Hydraulic handling of dredged material is by far the more common method. It is used to excavate and transport about 96 percent of the volume of material dredged each year.[42] Hydraulic methods include suction excavation and pumping through a submerged or floating pipeline from a pipeline dredge, direct pumpout from a hopper dredge moored at the disposal site, or a combination of the two methods.

Mechanical handling methods employ dipper dredges, bucket dredges, and ladder dredges. Mechanical methods are used especially in congested harbor areas for very small dredging projects, dredging of oversized debris, and secondary tasks such as dike building and clearing rehandling basins on major projects.

Two methods can be employed for land application of dredged material. Disposal can be accomplished via a pipeline directly onto land sites reasonably close to the dredging operations. Disposal in this manner results in the application of a slurry containing from 12 to 20 percent solids. This method can present problems similar to those resulting from the application of other solid waste slurries, namely runoff water quality and effects on groundwater quality.[42]

An alternative, and perhaps more practical, method uses predried or semidried, somewhat consolidated dredged material obtained from permanent dredged material containment facilities. Dredged material is deposited in a containment area, where it segregates into various particle-size distributions, consolidates somewhat, and begins to dry out. The dredged material can then be reworked, loaded into dump trucks or other suitable vehicles via a dragline or front-end loader, and transported to the land application site.

Land Application Potentials

The planned use of the application sites determines the potential of applying dredged material to land and is somewhat limited for highly contaminated material. Alternative uses of sites where dredged materials have been applied include: (a) agricultural production; (b) land improvement, reclamation of disturbed areas, and raising the elevation of lowlands; (c) wildlife habitat improvement and marsh, island, and upland habitat creation; (d) recreational facilities, park creation, and enhancement of golf courses; and (e) industrial and residential landfill. Alternative uses for highly contaminated material are limited to items d and e because of the potential of direct human or wildlife food-source contamination by these sediments. Ground or surface water contamination remains a problem with all of the above listed alternatives.[43]

Certain dredged materials are no doubt beneficial for agricultural production on specific land-application sites. All dredged materials, however, are not suitable for land application. The dredged material and the application sites have to be environmentally compatible.

The benefits of land application of dredged material are in some respects similar to the benefits of waste disposal on land. It is, emphasized, however, that soil improvements due to the application of wastes do not come automatically. Sound scientific management of waste material applications to the land is necessary to minimize the undesirable consequence that could result.

Legal Restrictions

Land application of dredged material will likely be subject to some of the same legal restraints imposed on land application of solid wastes, sludges, and wastewater. Accordingly, the environmental impact of land application of dredged material, including public health, social, and economic aspects, should be addressed. Environmental assessments will be required for all federally funded projects. Similar reports and surveys will probably be required by many state and local governments.

Among the public health effects that should be assessed are groundwater quality, possible breeding areas for insects and rodents, runoff from application sites, and chemical and biological contamination of crops. Groundwaters and runoff waters should be monitored for the presence of leachable contaminants from the dredged material. Nitrates are the most common problem, but other constituents such as soluble organics, dissolved salts, toxic metals, and human pathogens should be considered. Of all the federal and state laws stating public policy, the water quality legislation is the most pervasive.

These laws may, in effect, control what can be placed on land because of runoff problems and leachates reaching the ground water. For these reasons, extensive preapplication characterization, monitoring, and control practices should be planned.

Because there is a possibility of contamination from pathogens in the dredged material, conventional control methods for insects and rodents on a land application site should be practiced. Contamination of crops grown on dredged material is of general concern. While there are no specific regulations regarding crop contamination from dredged material, many states regulate the types of crop that may be grown with wastewater and the purpose for which those crops may be used. Similar regulations for crops grown on dredged material may be forthcoming.

Social and Physiological Concerns

The overall effects of specific land applications of dredged material should be evaluated in light of their impact on the sociological aspects of the community. Often the public has opposed the use of nutrient-rich waste, dredged material, or sludge close to their living environment. The objections usually are based on fear of foul odors, high concentrations of metals and trace elements, and the persistence of some pathogenic organisms. Local nuisance ordinances may be enforced in the case of nutrient-rich material that is malodorous while moist. It has been reported that odors from wastes can be minimized by thoroughly mixing and incorporating the materials into the soil.

Consideration should also be given to relocation of residents and the effects the operations will have on greenbelts, open space, recreational activities, and the quality of life. The large areas of land required for the application of dredged material may necessitate the purchase of land and possibly the relocation of residents.

Land application of dredged material should also be evaluated from an aesthetic point of view. Disruption of the local scenic character can be undesirable. Through proper design and planning, however, the beauty of the landscape can often be enhanced. Reforestation and reclamation of disturbed areas, such as those resulting from strip-mining operations, can be socially beneficial. The creation or enhancement of recreational facilities should be considered; for example, the application of nutrient-rich dredged material to golf courses may enhance grass growth.

Consideration should also be given to the economic impact of land application of dredged material. Factors that should be evaluated include change in land values, loss of tax revenues if governmental purchases are required, conservation of resources and energy, and change in quality of ground or surface waters.

Costs

The most variable constraint on the alternative disposal of contaminated dredged material will be the costs associated with transportation, land acquisition, and treatment and management of disposal sites. It will not be uncommon to find that land containment of highly contaminated dredged material will cost one or two orders of magnitude more than conventional open-water discharge or even open-water disposal with containment by capping. Average costs for dredging, land containment, and treatment of a PCB-contaminated river sediment in Seattle, Washington, in 1977 exceeded $50.00 per cubic yard. The disposal site was adjacent the waterway in this case. Harbor reclamation dredging and land containment in Japan have cost in excess of $50.00 per cubic yard ($65.00 per cubic meter) of material. If 10 percent of the material subject to annual dredging in New York Harbor required this level of containment and treatment, costs would be in the multimillion dollar range. Costs will also escalate with transportation distance and need for additional or special equipment. These cost and other considerations are discussed in detail in references 45 and 46.

Constraints on Disposal of Contaminated Dredged Material

A significant effort related to the disposal of contaminated dredged material is presented by Gambrell, Kahlid, and Patrick in their report on disposal alternatives.[15] Because of the usefulness of this report, relevant portions of the summary are presented in the following text.

The processes involved with the release or immobilization of most sediment-associated contaminants are regulated to a large extent by the physicochemical environment and the related microbiological activity associated with the dredged material at the disposal site. Important physicochemical parameters include pH, oxidation-reduction conditions, and salinity. Where the physicochemical environment of a contaminated sediment is altered by disposal, chemical and biological processes important to mobilization or immobilization of potentially toxic materials may be affected. In some cases, substantial contaminant release does not always result in greater mobility of a given contaminant. Frequently, an altered physicochemical environment that results in the release of contaminants from one chemical form will favor other immobilizing reactions. The influence of physicochemical conditions associated with various disposal methods on contaminant release must be identified.

In addition to the chemical properties of the contaminant, the chemical and physical properties of the dredged material can influence the mobility of contaminants at disposal sites. A number of readily

identified properties of dredged material affects the mobility and biological availability of various contaminants. Some of these properties can change when the sediment is moved from one type of disposal environment to another while other properties are not affected by changes in water content, aeration, or salinity.

The major sediment properties that will influence the reaction of dredged material with contaminants are the amount and type of clay, organic matter content, amount and type of cations and anions associated with the sediment, the amount of potentially reactive iron and manganese, and the oxidation-reduction, pH, and salinity status of the sediment. Much of the dredged material removed during harbor and channel maintenance dredging is high in organic matter and clay and is both biologically and chemically active. It is usually devoid of oxygen and may contain appreciable sulfide. These sediment conditions favor effective immobilization of many contaminants provided the dredged material is not subject to wave- or current-induced mixing, resuspension, and transport. Coarse-textured sediments low in organic matter content are much less effective in immobilizing metal and organic contaminants. These materials tend not to accumulate contaminants unless a contamination source is nearby. Should contamination of these sediments occur, potentially toxic substances may be readily released upon mixing in a water column or by leaching and possibly plant uptake under intertidal or upland disposal conditions.

Many contaminated sediments are initially anoxic and near neutral in pH. Subaqueous disposal into quiescent waters will generally maintain these conditions and favor contaminant immobilization. Certain sediments (noncal-careous and containing appreciable reactive iron and particularly reduced sulfur compounds) may become moderately to strongly acid upon gradual drainage and subsequent oxidation as may occur under upland disposal conditions. This altered disposal environment offers a high potential for mobilizing potentially toxic metals. In addition to the effects of pH changes, the mobility of most potentially toxic metals is influenced by oxidation-reduction conditions to some extent, and certain of the metals can be strongly affected by oxidation-reduction conditions. Thus, contaminated sediments that are coarse textured and low in organic matter content pose the greatest potential for release of contaminants under all conditions of disposal. Sediments that tend to become strongly acid upon drainage and long-term oxidation also pose a high environmental risk under some disposal conditions.

For sediments determined to represent a high environmental risk, disposal methods stressing containment of potentially toxic substances should be considered. Placement of dredged material heavily contaminated with potentially toxic substances in or adjacent to ecologically and economically important biological populations or in areas where productive habitat development will occur represents high-risk disposal

alternatives. Likewise, disposal in high-energy environments may not be a desirable alternative because of the greater probability of long-term dispersion and subsequent transport of contaminants. Contaminated sediments placed in low-energy regimes to minimize resuspension and transport of contaminated solids will reduce the environmental risk of disposal. The most effective physicochemical environment for immobilizing most potentially toxic metals is near neutral in pH, strongly reduced, and nonsaline, especially where sulfides are present.

Subaqueous Disposal

Subaqueous disposal of toxic dredged materials within or adjacent to especially productive aquatic systems represents a high environmental risk. Unconfined disposal in any moderate- to high-energy hydraulic regime also increases the environmental risk because of the likelihood of transport from the disposal site and chemical transformations of the contaminant to potentially more mobile and available forms as a result of altered physicochemical conditions in the receiving aquatic environment.

Unconfined disposal (where stable mounding will not occur) in moderate- to high-energy subaqueous environments has the inherent disadvantage of greater surface area exposure to water columns. This may contribute to greater transport across the sediment-water interface because of resulting shorter diffusion distances for the small amount of some contaminants that may be mobilized within the reduced dredged material as soluble complexes. Also, greater spreading will increase the surface area and thus the proportion of the total volume of the contaminated material that may become oxidized as a thin horizon at a sediment-water interface.

Certain subaqueous disposal alternatives offer the greatest potential for containment of potentially toxic substances associated with dredged material. Confined (stable mounding) subaqueous disposal of typically fine-textured, reduced dredged material will result in little long-term transport from the disposal site. This method will maintain a strongly reduced physicochemical environment and favors the stability of metal sulfide precipitates and insoluble complexes of metals with large molecular weight organic matter in the sediment. Confinement by mounding in areas of low biological productivity in a low-energy hydraulic regime not subject to storm currents should pose a very low potential for adverse environmental effects. For most purposes, this implies ocean disposal or other deep-water placement where depths are about 30 meters or greater. The optimal subaqueous disposal method, though not available for most projects, is confinement in a low-energy depression where the contaminated sediment can be covered with clean, wet material. These alternatives result in the

maintenance of reducing conditions favoring immobilization of most contaminants, minimum dispersion, and minimal surface area exposure of contaminated material to the water column and benthic organisms.

Short-term considerations. Elutriate test results and monitoring of water quality at disposal sites have generally shown that most contaminants are not released or are only released in negligible amounts during subaqueous disposal. Exceptions include manganese and ammonium-nitrogen for which short-term release in toxic concentrations may occur in the absence of mixing and dilution with receiving site water (which should rarely be a problem). Where small elevated levels of potentially toxic substances have been found in receiving site water, these levels usually decrease to predisposal levels quickly, often within minutes. Little short-term adverse impact of subaqueous disposal is expected for contaminated sediments out of a designated subaqueous disposal area because of dilution that will occur at the disposal site, the association of released contaminants with the solid phase, and the transient nature of any increase in the total levels of contaminants at disposal sites.

Little, if any, short-term adverse chemical impact on water quality or biological populations is expected within the disposal site. An exception would be very coarse-textured contaminated sediments that are low in organic matter and reactive iron contents from which substantial short-term contaminant release may occur. As previously mentioned, this type of contaminated sediment occurs only under very localized conditions near a waste outfall because coarse-textured sediments are not effective scavengers of most contaminants.

Long-term considerations. The greatest potential for adverse environmental impacts associated with contaminated sediments disposed of subaqueously would be long-term gradual release and biological accumulation. Typical fine-grained reduced sediments placed in a low-energy subaqueous environment should give mounding and immobilization of contaminants such that no long-term adverse effects will occur out of the designated disposal area nor in surface water quality within the disposal area. The potential for uptake by benthic organisms within the disposal area can be minimized by covering contaminated sediments with a layer of clean material.

Intertidal Disposal

Intertidal disposal of coarse-textured contaminated dredged material with low organic matter content may pose a high environmental risk because of the potential for leaching into adjacent groundwater or surface waters and probable greater plant availability of many contaminants. Intertidal disposal near especially productive or sensitive aquatic habitats also represents a high risk as does

extensive habitat development on some contaminated dredged material deposited intertidally. Covering the contaminated material with a clean layer of dredged sediment or soil should reduce the potential long-term impact of toxic material uptake by plants and animals. Physical confinement of the bulk dredged solids may be required to prevent erosion and subsequent dispersion of contaminated particulates into nearshore waters.

Intertidal disposal may present a higher environmental risk than subaqueous disposal because of greater hydraulic energy conditions at some intertidal sites contributing to erosion and dispersion of bulk solids, important and sensitive benthic and aquatic habitats usually associated with nearshore areas, and the demonstrated potential of plants to take up certain contaminants and cycle them into wetland ecosystems.

Short-term considerations. Unconfined intertidal disposal may result in elevated total contaminant levels in effluents associated with suspended solids during dewatering from initial consolidation and settling. Because of the proximity of most intertidal sites to important biological populations, such discharge should be minimized. It is anticipated that levels of suspended solids in effluent from any intertidal sites will be more difficult to control than for upland containment facilities where management to enhance suspended solids removal is more feasible.

Long-term considerations. Potential long-term problems of intertidal disposal of contaminated sediments will be associated with gradual erosion and dispersion of contaminated dredged material in nearshore areas and uptake and possible cycling by organisms that become established on these sites. These risks can be minimized by covering the contaminated sediments by a layer of clean material and by precautions to prevent gradual long-term erosion of contaminated particulates. Leaching of most contaminants into groundwater or adjacent surface waters may be a long-term risk only if the contaminated sediments are coarse textured with a relatively low organic matter content.

Upland Disposal

Upland confinement of contaminated sediments for disposal purposes can be done in an environmentally safe manner; although in many cases it may offer little or no benefit over certain subaqueous disposal methods. Sediments heavily contaminated with potentially toxic materials should not be applied upland for purposes of agricultural soil amendment or habitat development because of the potential for plant uptake, subsequent introduction into food chains, and possible human exposure from crop plants. Some sediments slightly to moderately contaminated with certain potentially toxic substances may be used for many upland purposes.

Water-saturated upland containment where leaching and biological colonization can be controlled on a long-term basis can be an effective disposal method for highly contaminated sediments as the maintenance of strongly reducing conditions favors immobilization of most potentially toxic substances. However, the long-term management problems and the relatively low capacity implied by water-saturated containment (i.e., dewatering permitted only by evaporation) makes this alternative feasible only for certain low-volume projects. Leaching control and the maintenance of long-term flooded conditions will favor immobilization of most metals as sulfide precipitates in sediments containing appreciable sulfur. Confined upland disposal with management to maximize suspended solids in initial dewatering effluents should be about as effective as water-saturated containment in containing most potentially toxic substances. Unconfined upland disposal not specifically intended for habitat development represents a moderate environmental risk because of the natural colonization and the implied greater initial spreading and resulting greater exposed surface area of contaminated sediment than will occur with confined disposal.

Except for very coarse-textured sediments with low organic matter and reactive iron contents, leaching of most contaminants into ground water or adjacent surface waters is not expected to be significant if the dredged material does not become strongly acid upon oxidation. Short-term leaching of iron and manganese and long-term leaching of some nitrogen forms may be exceptions. Upland disposal of toxic-metal-contaminated noncalcareous sediments containing large amounts of reactive iron and especially total or pyritic sulfide represents a *high potential* for long-term leaching. The strongly acid conditions associated with sulfide and pyrite oxidation will almost certainly result in substantial long-term mobilization and leaching of potentially toxic metals.

The use of contaminated dredged material for fill and other engineering purposes will present a low environmental risk under the following conditions:

- if extensive surface colonization by natural or managed biological populations is not permitted or the fill is covered with a layer of clean material greater than the expected rooting and burrowing depths of organisms;

- if organic matter, reactive iron, and silt and clay contents are moderate to high;

- if development of excessive acidity will not occur upon dredged material oxidation.

Short-term considerations. Short-term problems with upland disposal will be associated with elevated levels of contaminants associated with suspended particulates in initial dewatering effluents

from the confinement sites if applicable criteria for receiving surface waters are exceeded. Management to maximize suspended solids removal will be effective in reducing potential short-term release.

Long-term considerations. Potential long-term problems are associated with contaminant uptake and cycling by organisms and leaching into subsurface aquifers. Groundwater contamination may be a problem if strong acidity development is expected upon long-term oxidation of the dredged material. A dredged sediment containing appreciable sulfide or pyrite represents a high long-term risk for leaching and contaminating ground water with potentially toxic metals.

Liming the entire depth of an upland confinement facility for pH control may not be feasible for economic reasons and because of the additional disposal area capacity required to contain large amounts of lime. Liming may be an effective and feasible management tool for certain contaminated sediment materials applied as thin lifts for some land reclamation or soil improvement purposes.

Role of Contaminants in Selecting Disposal Alternatives

Most problem sediments will be contaminated with more than one toxic material. Thus, the environmental evaluation associated with the various disposal alternatives will often have to consider more than one contaminant and the relative environmental threat of each. An assigned ranking of environmental risks to each of the various contaminants is not possible because of their varying toxicities, varying levels of contamination, and differences in chemical behavior under different methods of disposal. However, it is prudent to suggest that a very high level of concern should be given to sediments determined to be contaminated with mercury, cadmium, and certain chlorinated hydrocarbons. Sediments with high levels of nitrogen, phosphorus, manganese, and iron generally pose a very low environmental threat under most disposal conditions. Anticipated environmental problems with sediments contaminated with lead, copper, zinc, nickel, chromium, arsenic, and petroleum hydrocarbons can range from high to low depending on many factors. In many cases, potential environmental problems with these contaminants tend to be more manageable, and there is more flexibility in disposal alternatives than for sediments contaminated with mercury, cadmium, and certain chlorinated hydrocarbons.

Mercury

Mercury is potentially one of the most hazardous of the toxic metals. Sediments highly contaminated with this element should be confined such that mercury is isolated at the disposal site. Dredged material with considerable levels of naturally occurring organic

matter and especially sulfide can effectively immobilize mercury. A reducing, near-neutral-pH disposal condition favors the long-term stability of sulfide and organic complexes and will thus minimize mercury release. For sediments with low to moderate levels of mercury, oxidizing conditions generally enhance release to a small extent compared to reduced conditions. At high levels of contamination, a moderately acid oxidized disposal environment may result in substantial release. Hydrous iron oxides can effectively scavenge traces of dissolved mercury in a water column. Increasing chloride levels may, however, reduce adsorption of mercury by hydrous oxides while increasing pH can overcome the chloride effect. Of the potentially toxic metals, mercury losses from upland confinement sites may be especially associated with the fine-particulate phase in initial dewatering effluents.

Cadmium

Cadmium, like mercury, is potentially a very hazardous element in the environment. Cadmium can be readily taken up and concentrated by plants and subsequently enter food chains. The chemical mobility and plant availability of cadmium are strongly affected by oxidation-reduction conditions. Furthermore, oxidizing conditions can substantially increase soluble cadmium levels and plant availability. This effect is accentuated by decreasing pH. Thus, the potential for environmental contamination from cadmium-contaminated dredged sediments may be enhanced at many upland disposal sites as a consequence of expected pH and oxidation changes that favor increased solubility, plant uptake, and leaching. Maintenance of a near-neutral-pH, strongly reducing disposal environment will be most effective in immobilizing cadmium.

Lead

Lead is a potentially toxic metal often found in contaminated sediments in very high concentrations compared to mercury and cadmium. Fortunately, it is less toxic in equivalent concentrations in soils and sediment-water systems. Excessive levels of lead in fine-textured soils and dredged material can be effectively immobilized by sulfide and sediment organics under reducing conditions. Immobilization by organics and hydrous iron oxides is almost as effective under oxidized conditions. Moderate to strongly acid oxidizing conditions that may develop in certain dredged material placed in upland disposal facilities may result in substantial long-term release of lead.

Hydrocarbons

Disposal methods that include long-term confinement of contaminated particulates should be effective in immobilizing chlorinated and petroleum hydrocarbon contaminants in contaminated sediments. There is no consistent effect of a given oxidation-reduction condition on the degradation rate of all chlorinated hydrocarbons, though the persistence of some do respond to altered physicochemical conditions. For sediments contaminated with petroleum hydrocarbons of low toxicity, disposal methods that permit gradual dispersion in oxidized water columns and surface sediments should pose a low environmental risk while enhancing their degradation.

Sulfur

In dredged material containing potentially toxic metals, the presence of reduced sulfur as sulfide can contribute to effective immobilization of toxic metals if disposal methods are selected to maintain the initial reducing conditions of the dredged material. On the other hand, long-term oxidation of reduced sulfur compounds in some dredged material under upland conditions can result in development of strongly acid conditions that can cause the release of substantial levels of toxic metals. This condition represents one of the greatest potentials for mobilization of toxic metals in dredged material.

Management Practices for Aquatic Disposal

Deep-ocean disposal at or beyond the outer edge of the continental shelf was thoroughly reviewed by Pequeqnat et al.[47] They evaluated the environmental aspects and impact of deep-ocean disposal, nearshore-offshore ecological trends and zonal analysis, and ecosystem dynamics and regional environments. Pequegnat et al. also considered factors such as those controlling spatial distribution and chemical fate, hydrobiological zones as disposal environments, and suitability of specific environmental areas for disposal of dredged material.[47] Based on the preceding considerations, they generally concluded deep-ocean disposal to be a viable alternative for highly contaminated material.

Gambrell et al. have shown that depositing contaminated dredged material into subaqueous depressions, where available, will be an effective method for immobilizing contaminants.[15] The formation of mounds that are stable in quiescent waters will also result in good containment of most contaminants. For additional protection, covering this highly contaminated dredged material with a layer of clean sediments will essentially seal the buried contaminants from overlying aquatic and benthic organisms. Covering will also help in isolating

the contaminated material from currents in low- to moderate-energy water columns and may minimize dispersion due to occasional storm currents. Furthermore, the increased diffusion distance coupled with the immobilizing processes within the clean layer will effectively prevent passive transport of trace amounts of contaminants from the depression or mounds by diffusion. Frequently, a large dredging project will include sediments with a wide range in levels of contamination. Dredging and mounding of the most contaminated material first, followed by covering with cleaner dredged sediments from the same project, may be very useful in confining and containing the most contaminated sediments.[15, 48, 49]

Morton demonstrated that, under certain conditions, the use of uncontaminated dredged material to cap contaminated sediment was an operationally feasible, cost-effective, and environmentally sound method for disposal in the marine environment.[48, 49] He found that the additional management and operational controls required to conduct these procedures were neither expensive nor complicated and were within the capabilities of today's dredging and disposal technology.

The operational feasibility of the capping technique has been demonstrated at a site in central Long Island Sound, and its application to slightly deeper waters on the shelf is currently being accomplished at the Mud Dump Site (ocean) in New York Bight.[50] Although initial indications concerning the environmental considerations of capping are favorable, continued monitoring should be conducted to determine if long-term effects such as sand/silt instabilities, bioturbation, storm effects, etc., reduce the effectiveness of the cap in isolating contaminants from the environment.

In general, then, it appears that the assimilative capacity of the ocean has not been exceeded at the approximately 120 sites which are being used for disposal of dredged material.

The Convention on the Preventon of Marine Pollution by Dumping of Wastes and Other Matter prohibits the ocean dumping of materials contaminated with other than trace contaminants of mercury, cadmium, organohalogens, and petroleum hydrocarbons.[51, 52] As a consequence of the aforementioned capping investigation, it is felt that dredged material contaminated with these chemicals can be regarded as containing a tracer of environmentally active contaminants and can be disposed safely at sea when followed by capping with clean material. Moreover, the capping process can be conducted in complete conformity with Annexes II and III of the convention through application of the Interim Guidance for the implementation of the convention. Capping has also been used in Canada with reasonable success in nearshore disposal sites (less than 20 meters in depth)[53] and should have application to sites up to 50 meters in depth.

There is obviously no simple solution to the disposal of contaminated dredged material, but when properly managed, the aquatic environment appears to offer a logical and environmentally sound alternative to land-based sites. The approach of carefully managing open-water sites should be considered a primary management solution to a perplexing problem. The same level of waste management should also be strictly applied to land containment of dredged material.

Conclusions

Based on the investigation reported herein, the following conclusions are considered warranted.

> There is no single disposal alternative that can be presumed to be suitable for a particular region or a group of projects; there is no single disposal alternative that can be presumed to result in impacts of such nature that it can be categorically dismissed from consideration.
>
> Impact on the water column during disposal appears minimal to nonexistent, and the effect is predominantly aesthetic in nature.
>
> Leaching of toxic metals from a subaqueous disposal mound into the water column appears no greater than from natural sediments of similar geochemical characteristics. Chlorinated hydrocarbon release to the solution phase was not detected in the laboratory or field. Nutrients were released in concentrations greater than background, but the disposal site mixing processes mitigated any effect.
>
> The major impact found at disposal sites was the physical mounding of the material. Benthic recolonization of the mounds appears relatively rapid on fine-grained sediments and somewhat slower on coarse-grained material.
>
> Bulk or total sediment analysis does not relate to any mobile or biologically available chemical fraction of a sediment, nor can it be used to predict or evaluate water quality and ecological perturbations.
>
> Studies of petroleum and chlorinated hydrocarbons uptake suggest minimal uptake from the solid phase of sediments with no transport out of the dump site.
>
> Studies of toxic metal uptake in the laboratory and in the field demonstrate minimal to no impact in freshwater, marine, and estuarine sediments. Measured effects were limited strictly to the dump site proper.

Land-based disposal methods can be considered to be more environmentally and sociologically complex than water-based alternatives.

Certain dredged materials are no doubt beneficial for agricultural production and specific land application sites; all dredged materials, however, are not suitable for these purposes.

Contaminant release from dredged material is related to the physicochemical environment and microbiological activity in the material at the disposal site. Land disposal represents the most significantly altered environment.

Capping an open-water disposal site and disposal in subaqueous depressions followed by capping offer environmentally sound approaches to disposal of contaminated dredged material.

Open-water disposal should be considered an acceptable method for disposal of dredged material, regarded as at least equal to all other alternatives, and considered throughout the planning process.

Open-water disposal of highly contaminated toxic dredged material can be considered a viable alternative when used in conjunction with appropriate site selection, capping, and long-term site management.

Domestic and international regulatory constraints are adequately met when capping and disposal site management are employed to isolate an unacceptable material from the aquatic environment.

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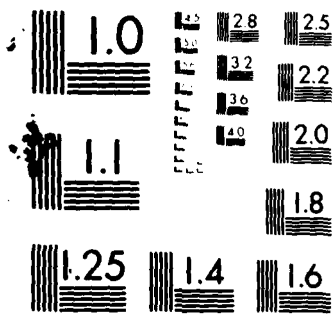

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FORTY-FOUR YEARS OF OCEAN DISPOSAL: A MUNCIPAL AGENCY'S EXPERIENCE AND RECOMMENDATIONS

by

Robert G. Arnold, Charles W. Carry, and Robert P. Miele*

Abstract

The County Sanitation Districts of Los Angeles County (hereinafter LACSD or Districts) have utilized the assimilative capacity of the Palos Verdes marine environment to aid in the disposal of treated municipal wastewater and sludge since 1937. Physical and biological evidence collected during the last decade suggests that, in some respects, past waste disposal practices have overtaxed that capacity, leading to unacceptable conditions, primarily among local marine sediments and the associated community of benthic invertebrates. Local environmental impacts are functionally related to the effluent solids content of the LACSD ocean discharge. A number of physical improvements have been undertaken over the years to reduce the suspended solids mass emission rate, stabilize solids whose discharge could not be eliminated, and control the use of local sewerage as a sink for toxic contaminants of industrial origin. Treatment improvements have generally accelerated the production of sludges at the Joint Water Pollution Control Plant (LACSD's central solids processing facility and source of the Districts' 370-mgd ocean discharge) and additional modifications are planned or under construction which will greatly intensify sludge processing and disposal problems. Solution of one environmental problem creates the potential for another.

Waste treatment and disposal planning is intimately related to the status of federal legislation, as well as the interpretation of environmental law by responsible agencies and the courts. In two areas, resolution of regulatory issues will greatly affect the Sanitation Districts' future use of the Pacific Ocean as a sink for treated municipal wastewaters and sludges:

(1) The Clean Water Act of 1977 established an avenue for marine municipal dischargers to avoid previously uniform secondary treatment requirements. Applications submitted to the Environmental Protection Agency (EPA) in September, 1979, are still under study or await final decision.

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(2) EPA, perhaps as a result of a recent court decision, is willing to modify its long-standing prohibition on ocean dumping of sewage sludge after December 31, 1981. There may or may not be implications in such action for pipeline disposal of sludges. Furthermore, criteria governing ocean dumping in general are likely to be redrafted by EPA during 1981. Again, the implication for future LACSD sludge disposal plans is unclear.

In this paper, the authors intend to expose the relative economic and environmental costs which are estimated to attend alternative decisions regarding (a) the LACSD application for waiver of secondary treatment requirements, and (b) future sludge disposal practices by the Districts. Acknowledging unavoidable uncertainties, we have used these projected costs to propose a more or less rational course for EPA to follow in regulating the disposal of municipal wastes in Southern California marine waters.

Preface

The propriety of discharging wastewater effluent and sewage sludge within the marine environment should be evaluated relative to the probable environmental and economic costs of disposal via alternative means. Monitoring and research activities conducted within the last ten years have produced a reasonable body of oceanographic data with which to estimate the probable environmental effects of marine disposal activities. Although our comprehension of individual mechanisms affecting marine assimilative capacity is incomplete, a set of more or less empirical cause-effect relationships has evolved which permits estimation of related environmental consequences. Remaining uncertainties, although significant, are frequently no more severe than those which beset analysis of alternative waste disposal activities.

It is not surprising that economic and environmental costs associated with individual disposal activities cannot be meaningfully combined to yield a single project cost figure, or that the balance between economic and environmental interests remains an essentially subjective issue. It is the responsibility of agencies charged with wastewater pollution control to expose related economic and environmental costs so that difficult decisions may be made on the most rational possible basis. The Districts hope to discharge that responsibility, as related to specific marine disposal issues, in the accompanying text.

This paper is organized in four parts. The first (Introduction) consists of descriptions of: the Sanitation Districts; the agency's dependence on the local marine environment as a sink for

treated municipal wastewater; and marine pollution events, treatment process modifications, etc., which provide perspective for marine disposal issues. The second and third parts are discussions of two related marine disposal questions of great importance--issuance of secondary treatment variances for POTWs (publicly owned treatment works) discharging to marine waters and advisability of marine sludge disposal--from the Sanitation Districts' point of view. Here, we have attempted to document or project the environmental effects and economic costs of alternative pollution abatement strategies. Finally, we have proposed a set of fairly broad recommendations related to the disposition of wastewater and sludge disposal issues facing Southern California municipalities.

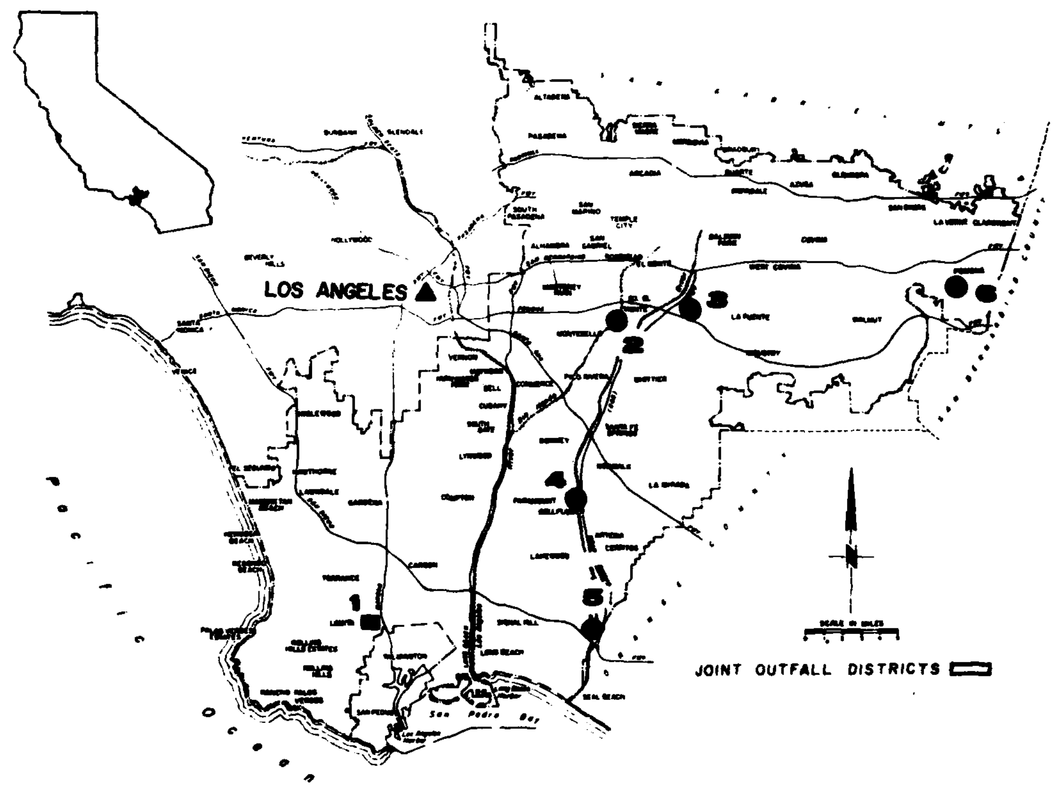
What our paper fails to do is directly confront the issue of waste assimilative capacity within the marine environment. Such capacity cannot be estimated without first defining those environmental impacts, or symptoms of such impacts, which are unacceptable. Such a determination is beyond our ability; we have limited ourselves to the smaller task of exploring costs attributable to disposal alternatives in our own environmental setting.

Introduction

The County Sanitation Districts of Los Angeles County (LACSD or Districts) serve the sewage treatment needs of nearly four million people and numerous, diverse industries in Los Angeles County, excluding, however, the city of Los Angeles, which operates its own waste disposal system. Founded in 1923 as a regional collection, treatment, and disposal system for community wastes, the organization has evolved to encompass 27 districts serving all or parts of 75 cities and more than 40 unincorporated communities. A subset of 15 contiguous districts in the urbanized Los Angeles Basin comprise the Joint Outfall Districts (JOD). The geographical area encompassed within the JOD extends south and west from the San Gabriel Mountain foothills to the Palos Verdes Peninsula and Pacific Ocean. San Bernardino and Orange Counties form the eastern boundary, and the cities of Glendale and Los Angeles form the western limit of the area as shown in Figure 1. Over the years, the JOD have built an integrated network of facilities known as the Joint Outfall System (JOS), which includes six treatment plants, 1,000 miles of interceptors and trunk sewers, and two actively used submarine outfalls. The JOS serves an urban area of 615 square miles, including approximately 70 cities, over 30 unincorporated communities, and an estimated population of 3,650,000. Residential and industrial flows in the JOS currently average 450 million gallons per day (mgd).

joint outfall system

sanitation districts of los angeles county



1	joint water pollution control plant	4	los coyotes water reclamation plant
2	whittier narrows water reclamation plant	5	long beach water reclamation plant
3	san jose creek water reclamation plant	6	pomona water reclamation plant

Figure 1

Characteristics of the Joint Outfall System

The JOS consists of two major treatment subsystems:

(1) The Joint Water Pollution Control Plant (JWPCP), a 385 mgd capacity sewage treatment plant, provides a "gravity" flow terminus for the trunk sewer network. The plant serves two distinct functions. It provides: (a) advanced primary treatment for approximately 80 percent of the JOS flow prior to ocean disposal via deep ocean outfalls, and (b) central solids processing for the JOS. Most of the industrial flow generated in the JOS is tributary to JWPCP.

(2) Five inland water reclamation plants (WRPs), which nominally have a combined capacity of about 110 mgd, provide tertiary treatment for 20 percent of the JOS flow prior to reuse or discharge to the San Gabriel River system.

Treatment plant locations are shown in Figure 1. All six treatment facilities shown are connected by a network of interceptors which (1) provide a degree of flexibility in selecting residential, low mineral content wastewaters suitable for reclamation and (2) permit return of sludges generated at the WRPs to the sewer system for eventual downstream processing at JWPCP.

The JWPCP Plant and Outfall

The JWPCP is located six miles inland from the Pacific Ocean in the City of Carson. (See Figure 1.) The plant presently provides advanced primary treatment, consisting of bar screening, aerated grit removal, primary sedimentation, skimming of floatables, and fine-mesh screening. Polymer addition ahead of the primary sedimentation tanks increases the solids removal efficiency of these units.

Material which settles or is skimmed during sedimentation (primary sludge) is anaerobically digested and dewatered via centrifugation. Dewatered cake is either landfilled or composted for sale as soil amendment. Due to a chronic shortage of dewatering capacity, a significant portion (approximately one-third) of the digested primary sludge is discharged to the ocean in the form of centrate from the dewatering step.

During normal operations at JWPCP, treated wastewater is discharged to the Pacific Ocean off Whites Point via two outfalls, hereinafter referred to as the 90-inch and 120-inch outfalls. A 72-inch outfall, active previous to construction of the two currently in use, is occasionally utilized to provide relief during exceptionally wet periods when plant flows exceed the hydraulic capacity of

the two-outfall system. Such high-flow conditions are infrequent (the 72-inch outfall has been used on about 20 relatively brief occasions since 1966). A fourth outfall (60-inch) exists but was removed from service in 1958 and will not be used in other than emergency situations. Locations of the outfalls relative to the Palos Verdes Peninsula and Shelf are shown in Figure 2.

Both the 90-inch and 120-inch outfalls are equipped with multiport diffusers. Port diameters increase in the downstream direction in a manner designed to maintain more or less equal port flows under a broad range of discharge conditions. Both diffusers lie on a slope; effluent is discharged from the 90-inch outfall between 58 and 63 meters, while the 120-inch outfall discharges between 48 and 57 meters. The minimum initial dilution provided by the outfall-diffuser system is on the order of 100:1. Characteristic dilution estimates are considerably higher.

JWPCP Effluent Quality and Related Marine Effects

In the past, pollution control measures were designed to meet aesthetic considerations and public health standards related to the potential for disease transmission from water contact. Thus, the practice of discharging JWPCP primary effluent along with centrate containing digested sludge solids was thought to provide the proper balance between treatment cost and environmental protection. More recently, the perception of environmental problems has grown significantly more acute, and both the scientific community and the general public have shown an increased concern for the health of the marine environment. State and federal standards for marine discharge have grown correspondingly more stringent.

By 1970, marine monitoring indicated that discharge practices at Whites Point were the source of significant impacts within the local marine environment. The most disturbing of these were (1) the disappearance (around 1959) from the area off the Palos Verdes Peninsula of the once extensive beds of kelp (covering around 1,750 acres in the 1920s), along with elements of sea life which they supported, and (2) interference in the reproductive cycle of the California brown pelican and California sea lion. The latter problem is widely attributed to the local manufacture and discharge of large quantities of DDT, high concentrations of which accumulated in sediments and biota over a wide geographic area. More extensive marine monitoring over the past decade has exposed more subtle impacts of waste discharge which will be discussed subsequently.

In response to these and other environmental problems, a number of positive steps were taken during the last ten years to improve the quality of JWPCP effluent. Following elimination of the influx of DDT to the JOS in 1970, the most obvious signs of DDT poisoning

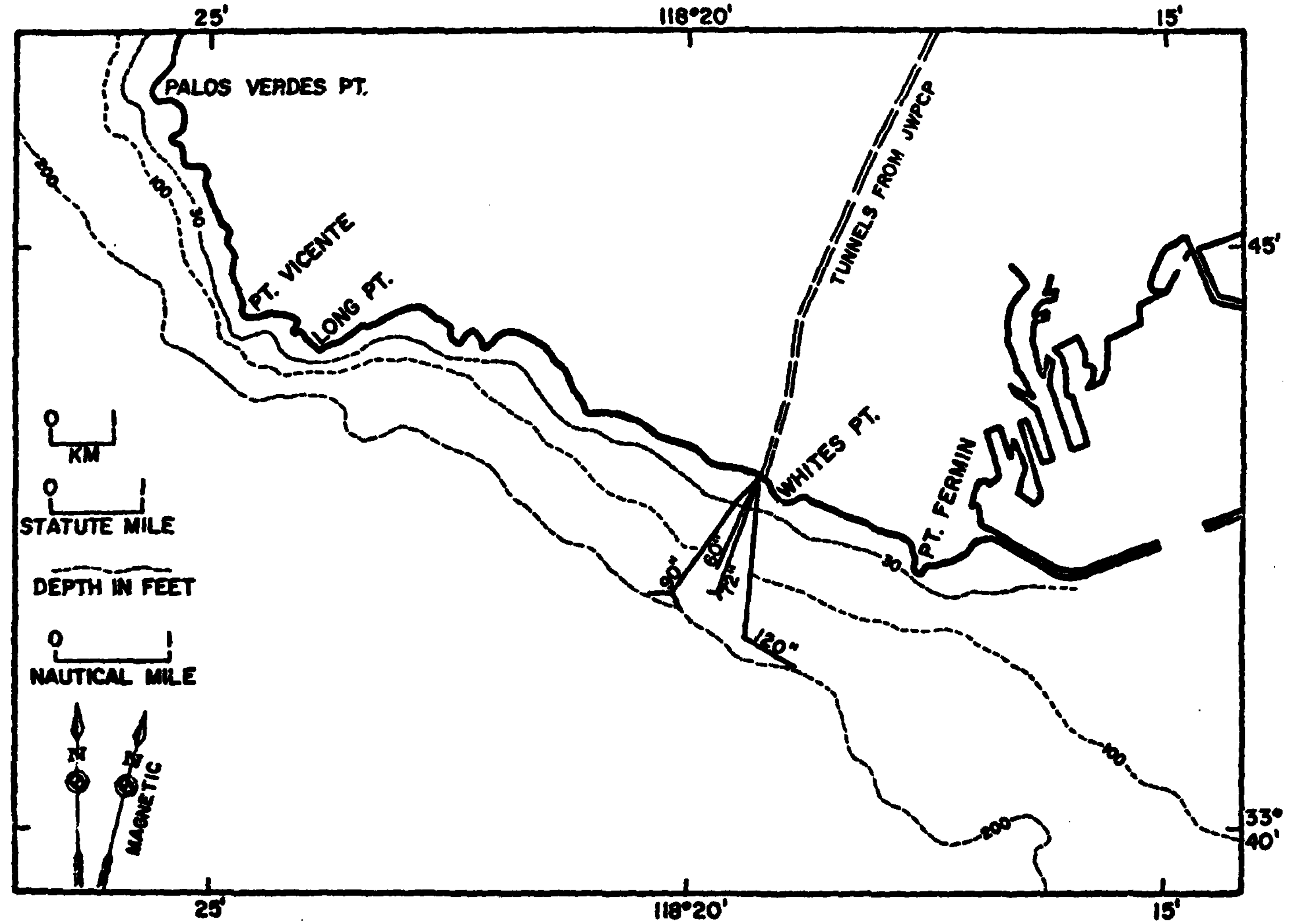


Figure 2. Position of JWPCP Outfalls Relative to Features of the Palos Verdes Coastline and Shelf.

disappeared. In January, 1975, the Sanitation Districts announced industrial waste discharge limitations designed to eliminate the capricious discharge of specific toxicants to the JOS by contributing industries. Enforcement of announced limits began in mid-1977. Treatment process modifications at JWPCP included increases in sludge digestion and sedimentation tank capacity, construction of effluent screens, and the addition of polymer ahead of primary sedimentation. These measures, along with the construction of additional dewatering (centrifugation) facilities, operational in January, 1977, significantly reduced the overall discharge of toxic materials and solids to the ocean. Despite these improvements, emissions of several wastewater constituents (most notably, suspended solids) continue to exceed limits established within the California State Ocean Plan.[1] The annotated record of monthly average JWPCP suspended solids emissions is provided as Figure 3.

As a result of treatment process improvements and industrial source control measures, levels of DDT in fish and shellfish taken near the outfalls have decreased, and the nestling count of California brown pelicans on Anacapa Island increased from near zero in 1970 to 300 in 1974. However, it is estimated that residual DDT and PCB in the JOS sewer system will delay their complete elimination from the JWPCP discharge indefinitely. Furthermore, past discharges have created a reservoir of refractory organics in the local sediments which will remain a substantial source of toxic materials in the marine environment for an extended period.

Reestablishment of Palos Verdes kelp forests has been assisted by California State Department of Fish and Game personnel and others. Aerial surveys indicate that a 16-acre canopy of kelp present in 1974 has expanded to approximately 640 acres. Effluent solids reductions at JWPCP probably contributed to the observed kelp recovery through enhancement of light penetration and reduction in toxic emissions.

Upgrading Treatment at JWPCP

Despite the improvements noted above, there remains ample reason to suspect that more effective sewage treatment at JWPCP would substantially enhance biological conditions among marine waters and sediments off the Palos Verdes Coast. As a consequence, the Sanitation Districts are committed to construction and operation of partial secondary treatment facilities at the JWPCP. As used herein, partial secondary treatment includes, in addition to equipment already in place, biological treatment facilities with a design capacity of 200 mgd and additional solids processing equipment necessary to effectively dewater and dispose of all sludges produced within the plant. Sludge disposal alternatives are discussed below. Partial secondary treatment is predicted to result in an effluent concentration of approximately 90 milligrams per liter (mg/l) suspended solids and 90

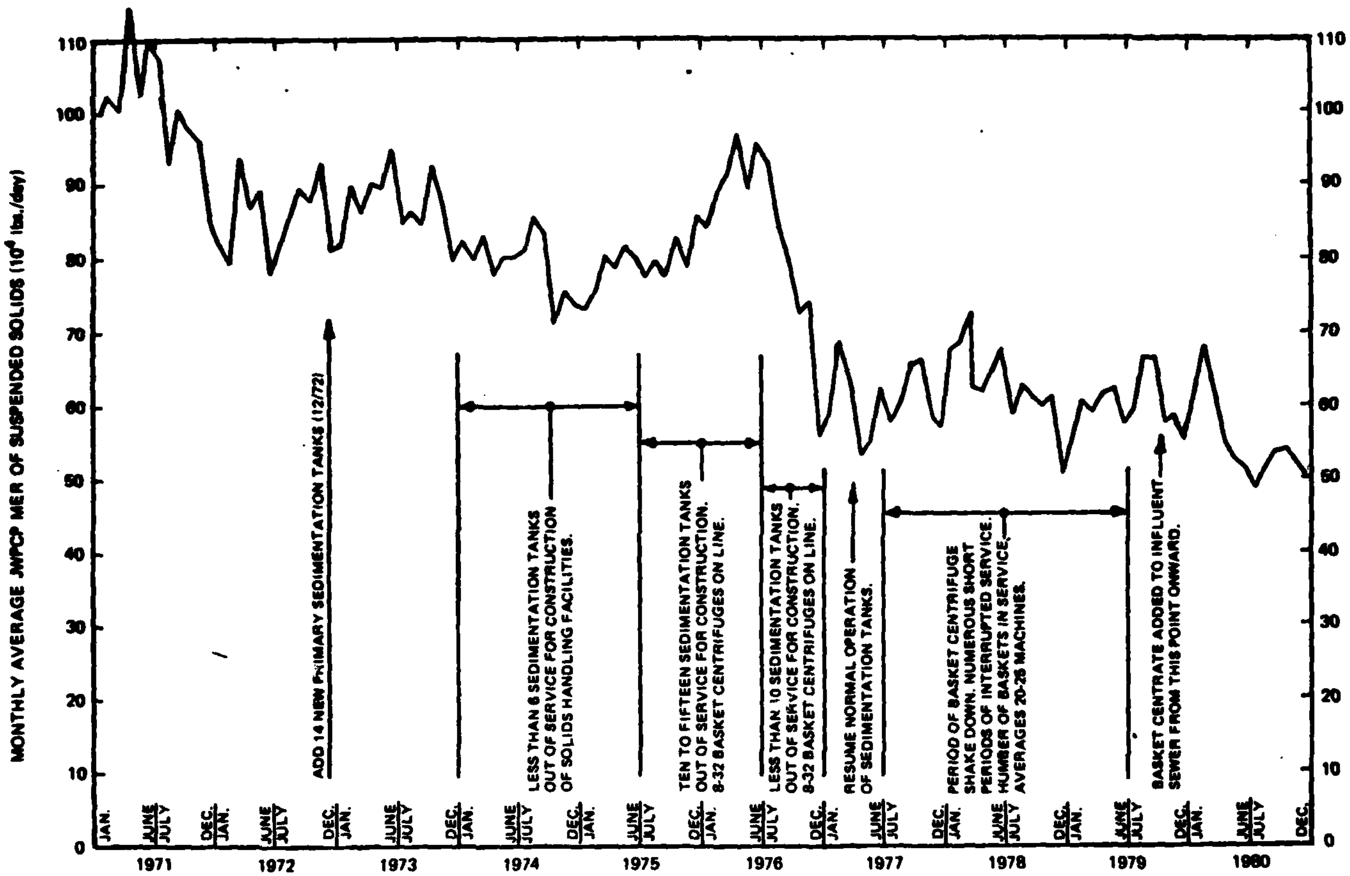


Figure 3. Annotated Record of JWPCP Suspended Solids Mass Emission Rate (1971-1980)

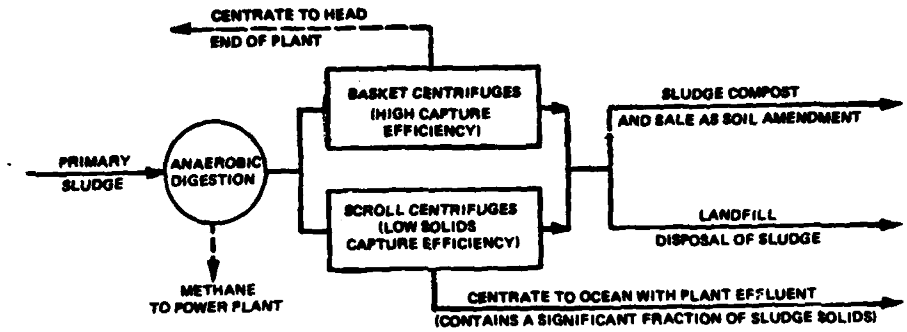
mg/l five-day biochemical oxygen demand (BOD_5 20°C). Although such an effluent does not satisfy EPA's definition of secondary treatment, it would meet apposite standards of the California State Ocean Plan, and the Sanitation Districts have applied for a modification of secondary treatment requirements at JWPCP under Section 301(h) of the 1977 Clean Water Act (P.L. 95-217) on that basis.[2] Disposition of the application is pending.

Sludge Disposal Planning - The LA/OMA Project

Currently, the 350 dry tons per day (dtpd) of digested sludge produced at JWPCP is disposed of via a combination of (1) composting for sale as soil amendment (70 dtpd), (2) landfilling (150 dtpd), and (3) ocean discharge (130 dtpd) as centrate with sewage effluent via the Whites Point outfalls. In 1974, the Sanitation Districts, in concert with other local operating agencies, EPA, and the State Water Resources Control Board, organized the Los Angeles/Orange County Metropolitan Area Sludge Management Project (LA/OMA) to identify and evaluate disposal alternatives for sewage sludges developed within the Los Angeles Basin. In November, 1980, the LA/OMA Project recommended sludge management programs for each of the major wastewater treatment agencies in Orange and Los Angeles Counties. The recommended plan for the Sanitation Districts consists of: upgrading the existing sludge composting program to dispose of approximately 100 dtpd, although the effect of subsequent federal regulations related to the use of sludge-derived products is uncertain; dehydration and incineration for direct energy recovery from 250 dtpd of digested, dewatered sludge; and landfill disposal of remaining sludge (approximately 150 dtpd). Figure 4 shows process schematics for sludge processing facilities proposed within the LA/OMA Project and those in existence.

Methods for Comparing Treatment Alternatives

The Sanitation Districts have attempted to estimate the relative economic and environmental costs of (1) the practice of partial secondary treatment as opposed to full secondary treatment at JWPCP, and (2) marine disposal of JWPCP sludges via a separate deep ocean outfall versus implementation of the LA/OMA recommended plan. In this analysis, the economic cost of not receiving a waiver is equal to the difference between capital and operating costs attributable to the practice of full versus partial secondary treatment. The environmental costs of waiver approval are equal to differences in local marine conditions which are projected to result from these two alternative treatment practices. Similarly, the cost of a prohibition against deep ocean sludge disposal is estimated by contrasting the economic costs of (1) implementing the selected LA/OMA plan for the Sanitation Districts, and (2) constructing and



4(b). LA/OMA Project Solids Processing and Disposal Recommendation for JWPCP

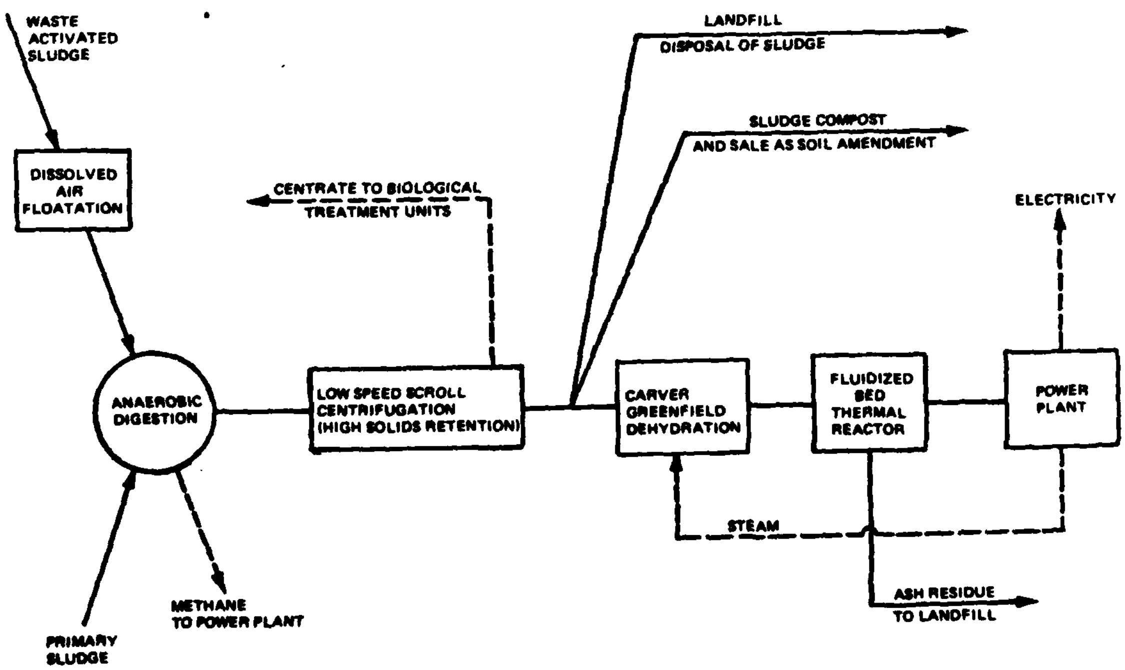


Figure 4. Schematic Representation of Present and Projected (LA/OMA Recommended Plan) Solids Processing and Disposal Systems at JWPCP.

operating a sludge outfall system designed to discharge digested sludge to the San Pedro Basin at a depth of perhaps 1,000 feet. The benefit of such a prohibition must be estimated on the basis of probable environmental consequences projected to result from alternative sludge disposal practices. The uncertainties involved in such a comparison are enormous, and so risks (e.g., risk of environmental degradation in excess of projected levels, risk of irreversible environmental damage, risks of technological failure, etc.) are considered.

Remaining material is divided into three parts. The question of waiver of secondary treatment requirements at JWPCP is considered first, followed by a discussion of sludge disposal alternatives. The paper concludes with a set of recommended actions in these two related areas.

Secondary Treatment Waiver for JWPCP

Legislative Background

The following sequence of legislative and regulatory events produced the existing situation in which many marine dischargers await federal evaluation of applications for waiver of secondary treatment requirements.

(1) The 1972 Clean Water Act (P.L. 92-500) and subsequent federal regulations established minimum treatment for all publicly owned treatment works at the secondary treatment level. Those responsible for administering the Federal Water Pollution Control Act (amended by P.L. 92-500) maintained that the uniformity provided by minimum treatment requirements was more important to achievement of pollution abatement goals, and therefore to the public welfare, than was the relative economic efficiency that might result from alternative pollution abatement strategies.

(2) Coastal municipalities reacted to the imposition of uniform secondary treatment requirements by stating that in some marine disposal settings wastewater constituents which secondary treatment was designed to control (and in terms of which the Environmental Protection Agency had defined secondary treatment--biochemical oxygen demand and suspended solids) do not present an environmental problem. In such cases, uniform effluent standards were held to represent a glaring inefficiency.

(3) In 1977, Congress again amended the Federal Water Pollution Control Act to include Section 301(h), which set forth criteria for modification of secondary treatment requirements. The criteria apply only to municipalities discharging to marine waters, as defined within the Act. Congress stipulated that such modified

treatment must result in both satisfaction of applicable water quality standards devised in lieu of secondary treatment effluent requirements and protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife.

(4) The Environmental Protection Agency subsequently devised a comprehensive set of regulations governing applicants for waiver of secondary treatment requirements.

In the Sanitation Districts' waiver application, it is contended that the practice of partial secondary treatment would result in essentially the same level of environmental quality among the Palos Verdes receiving waters and shelf sediments as would elimination of the Whites Point discharge. Such a demonstration is required within the EPA waiver regulations. However, the Districts believe that a more relevant comparison (and that which is developed in material which follows) involves environmental conditions predicted to follow implementation of full secondary versus partial secondary treatment at JWPCP.

Discharge-Related Anomalies Among Local Marine Biota

Local communities of phytoplankton, pelagic fishes, and intertidal species are excluded from this discussion because they are typically indistinguishable from similar communities in regions unaffected by waste discharges. The creatures which are impacted most noticeably by the discharge of pollutants on the Palos Verdes Shelf are bottom dwellers. Their feeding habits and lack of mobility make benthos ideal indicator organisms for assessment of outfall induced changes in the marine environment. It is also true that anthropogenic pollutants, such as persistent organics and heavy metals, tend to aggregate on sewage particulates, an appreciable fraction of which are deposited among the local sediments.

Apparent deficiencies in the local benthic community are related to the introduction of several types of outfall-related pollutants into the sediments. The rather massive discharge of particulate organics has generated anaerobic conditions over a portion of the Palos Verdes Shelf and production of hydrogen sulfide in sediment pore water. Characteristics of such areas include decreased species diversity and biomass; farther from the outfall, abundance and biomass are enhanced relative to unaffected communities, but diversity remains depressed. Other indicators of community structure, such as the infaunal trophic index (ITI), a numerical indicator of the dominant feeding strategies among benthic invertebrates, are depressed over great portions of the Palos Verdes Shelf. (See Figure 5.)

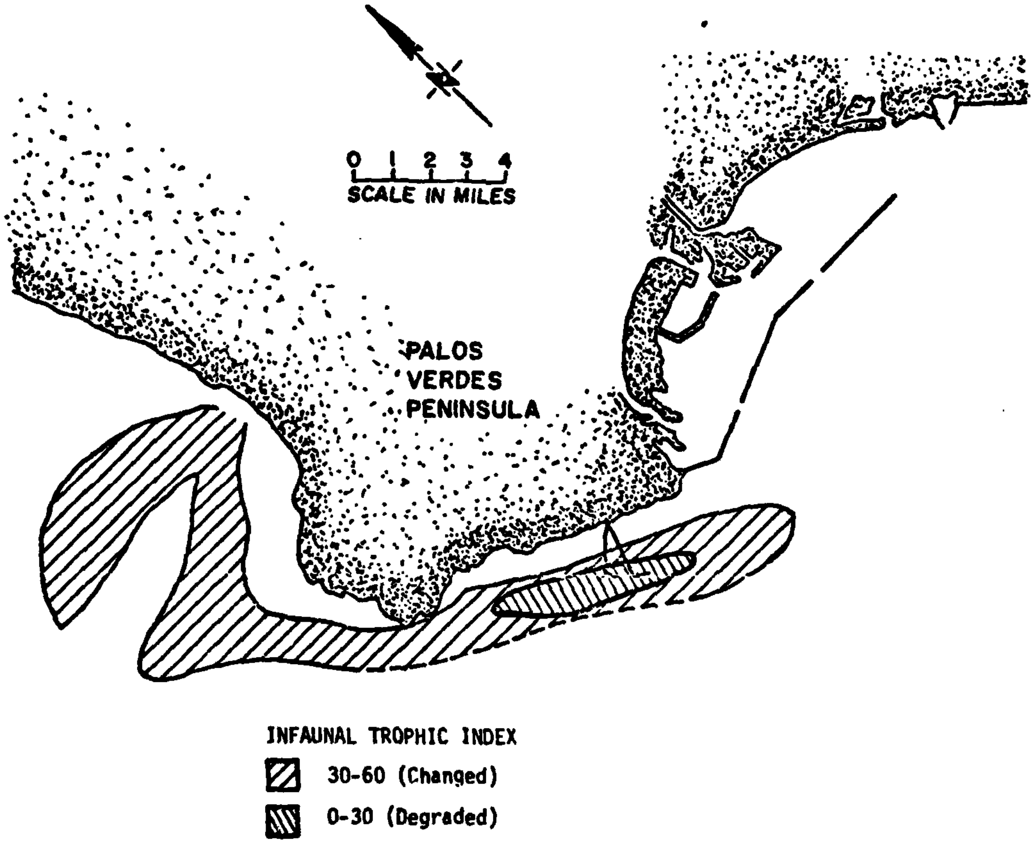


Figure 5. Distribution of "changed" and "degraded" Benthic Infaunal Communities on the Palos Verdes Shelf, as indicated by Infaunal Trophic Index (ITI) calculations. Normal communities (unshaded) are dominated by suspension-feeding species of invertebrates (ITI>60); changed communities by surface-deposit-feeders; and "degraded" communities by subsurface-deposit-feeding invertebrates (ITI<30).

Results are based on Bascom Survey (SCCWRP) conducted among Southern California soft-bottom sediments (1978-79).

Heavy metals, pesticides, and other toxic organic chemicals (such as PCB's) are also commonly associated with sewage particulates. Over years of sewage disposal via the Whites Point outfalls, many of these toxicants have accumulated in the local sediments posing problems for benthic invertebrates. Bioaccumulation of heavy metals, DDT, and PCB's have been observed among various organisms, e.g., Mytilus californianus (intertidal, filter-feeding mussels). Furthermore, it is felt that high sediment concentrations of DDT have led to the exclusion of several important groups of benthic organisms (crustaceans and echinoderms) from the Palos Verdes Shelf.

The same physical, outfall-related effects that led to structural anomalies among the benthic community are also responsible for biotic deficiencies within the rocky subtidal area. Aside from the inhibition of kelp growth (see Introduction), the Districts' discharge is felt to have severely altered abundance and structure in the local rocky subtidal community. Depression of percent coverage and diversity and the general absence of expected sessile species are particularly noticeable at the 12- and 18-meter depths at and immediately northwest of the outfall structures.

Demersal fishes have been affected by discharge practices off Whites Point. Sediment quality in the outfall vicinity is the probable cause of fin erosion—especially among locally abundant Dover sole—and liver enlargement. In addition to abnormal disease incidence, the local community of demersal fishes has been disturbed more subtly in several respects. Departures from normal community structure include enhancement of some species and depression of others in terms of abundance. Noticeable alterations in community function include deficiencies in the normal feeding structure, as evidenced by the loss of species that fill specific roles. The yellowchin sculpin, which feeds on crustaceans (now absent or substantially reduced off Palos Verdes due to the presence of DDT in local sediments), provides an example of such a loss. In addition, several species that normally fill specific feeding roles have been replaced by more pollution-tolerant species.

Predicted Recoveries Following Alternative Treatment Improvements

The effect of either partial or full secondary treatment at JWPCP on the local benthic community is expected to include compression, and perhaps disappearance, of the region characterized by low abundance and low species diversity as well as significant reduction in the area currently characterized by biomass enhancement and diversity depression. Improvements in community structure are expected across the entire Palos Verdes Shelf. However, it is predicted that the benthic community in the zone of greatest impact will not fit EPA's description of a balanced indigenous population at any time in the foreseeable future. The Districts believe that

this condition will be attributable to persistent effects of past sewage disposal practice, as opposed to the modified Whites Point discharge.

These conclusions are based on mathematical models which were utilized to forecast Palos Verdes surface sediment chemical and benthic biological qualities following implementation of alternative treatment process improvements. By far the most complex and important of these is a sediment deposition and mixing model which was used to predict surface sediment concentrations of organic carbon total DDT, and several trace metals as functions of time position relative to the Whites Point discharge, and level of treatment provided. Input data include: (1) representative wastefield particulate settling velocity distribution, (2) local current characteristics, (3) data representing past and predicted JWPCP effluent qualities, and (4) sediment mixing and resuspension parameters. A schematic illustration of model components is provided as Figure 6.[3] Representative output (predicted sediment concentrations of total organic carbon, chromium and DDT per alternative treatment conditions) is provided in Figures 7 through 9. The significance of model results is explained subsequently.

A number of qualitative models were utilized to project biological characteristics across the Palos Verdes Shelf. These relied on sediment chemistry predictions developed in the manner described above. Improvements in the benthic community predicted to follow implementation of partial secondary treatment at JWPCP include a reduction in the dominance of annelids and an increase in molluscan biomass in the area of greatest outfall-related impact. Elimination of anaerobic, sulfide-bearing sediments will result in recovery from related biological deficiencies. Bioaccumulation of persistent organics and heavy metals in benthic animal tissues is expected to be less severe following implementation of partial secondary treatment (primarily as a result of effective industrial waste pretreatment). Existing data indicate that surface sediment concentrations of metals and DDT have declined significantly during this decade in response to the Districts' industrial waste source control program. Animal tissue concentrations have also declined, although not in proportion to sediment improvements.

Expected residual deficiencies in the benthic community following implementation of partial secondary treatment at JWPCP include continued local depression of infaunal trophic index values (indicative of altered community structure) and (infrequently) unacceptable concentrations of specific toxicants in animal tissues. Enhancement of total biomass and depression of diversity are expected to characterize the area of most aggravated outfall-related impact throughout the remainder of the twentieth century. The return of crustaceans and echinoderms to the area of greatest outfall related impact is not immediately expected due to the local persistence of excessive trace toxicant concentrations.

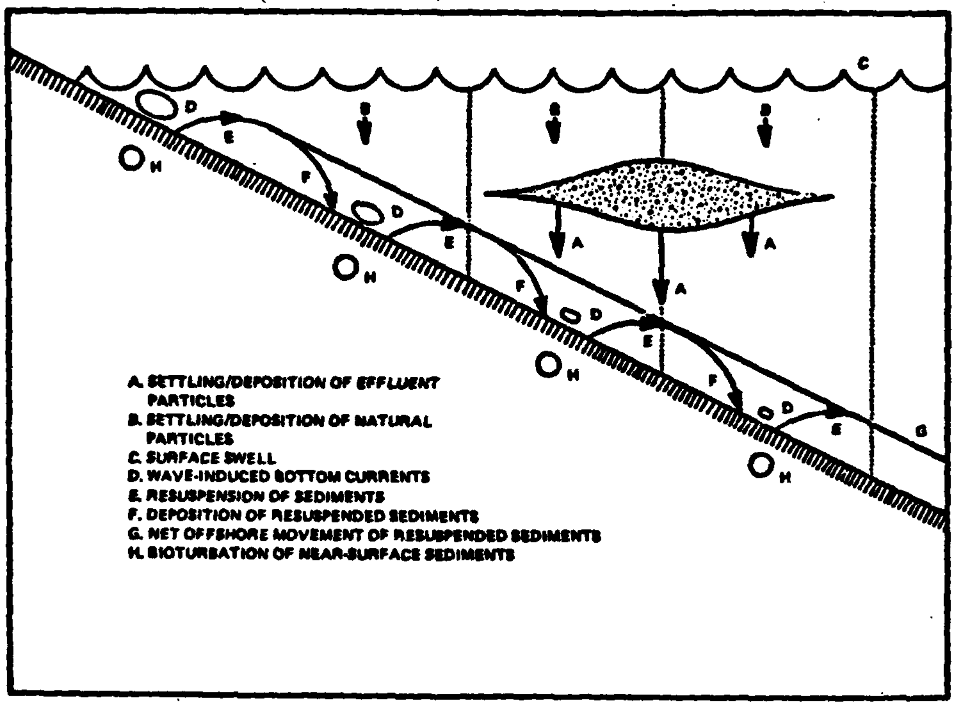
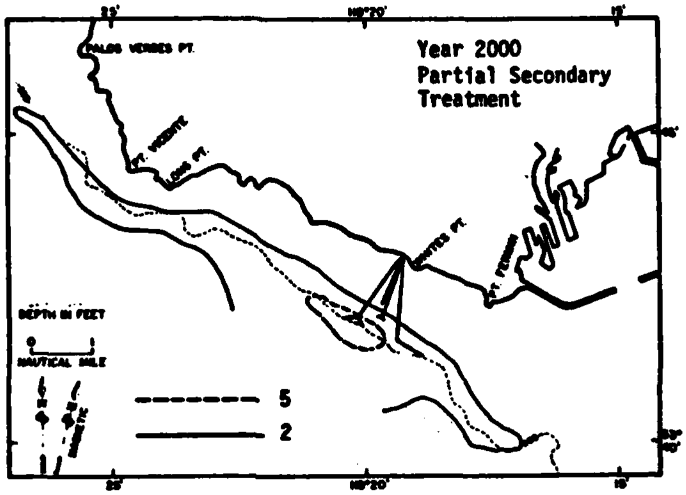


Figure 6. Conceptual Illustration of Hendrick's Particulate Deposition and Sediment Mixing Models (From 1978 SCCWRP Annual Report).



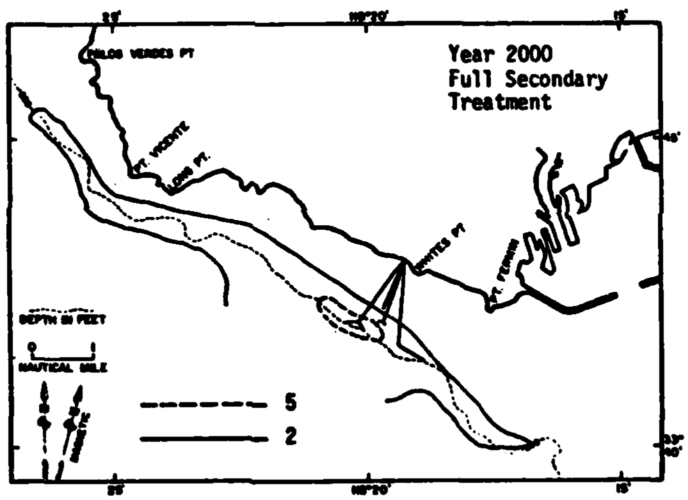


Figure 7. Predicted Year 2000 Concentrations of of Total Organic Carbon among Palos Verdes Shelf Surface Sediments (Percent Dry Weight). Predictions Correspond to Partial and Full Secondary Treatment Scenarios at JWPCP (See Text for Explanation).

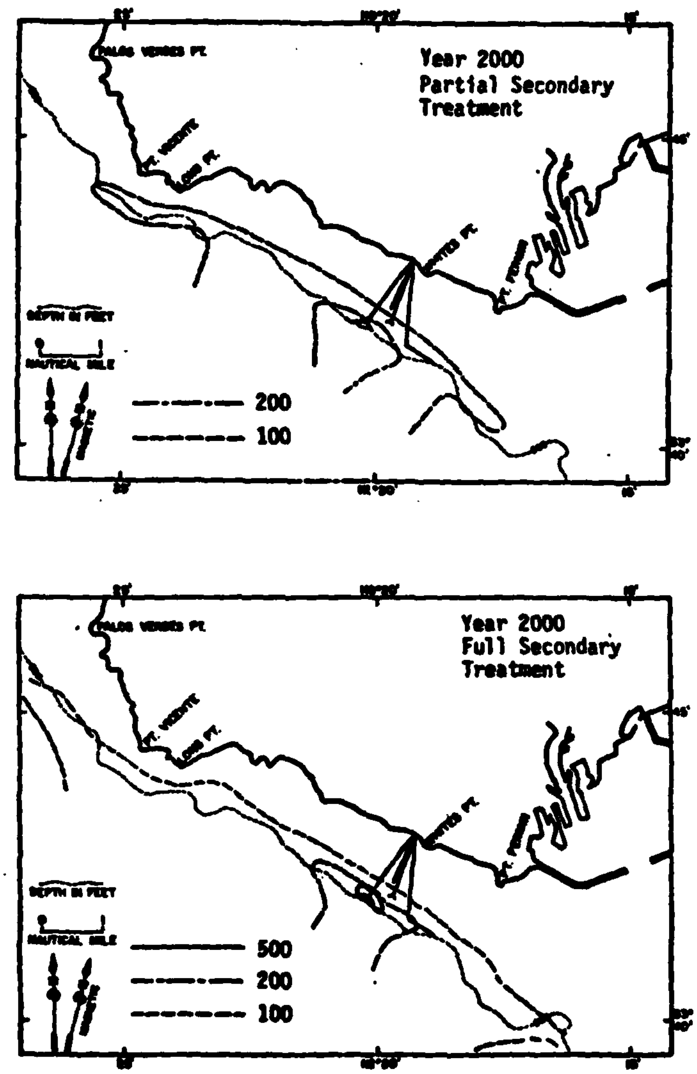
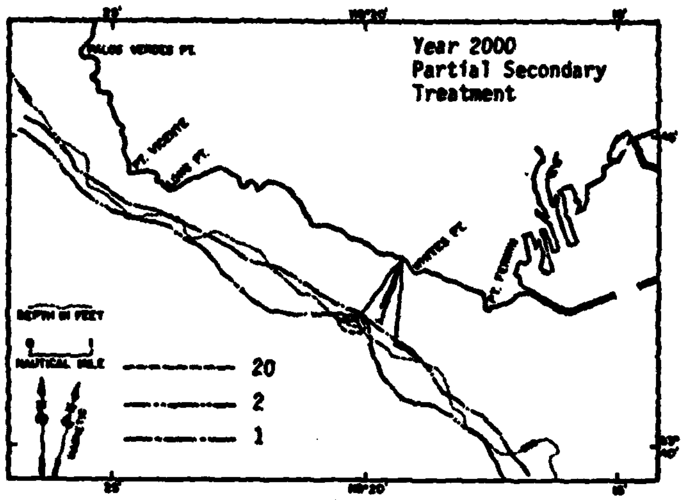


Figure 8. Predicted Year 2000 Concentrations of Chromium among Palos Verdes Shelf Surface Sediments (mg/dry kg). Predictions correspond to Partial and Full Secondary Treatment Scenarios at JWPCP (See Text for Explanation).



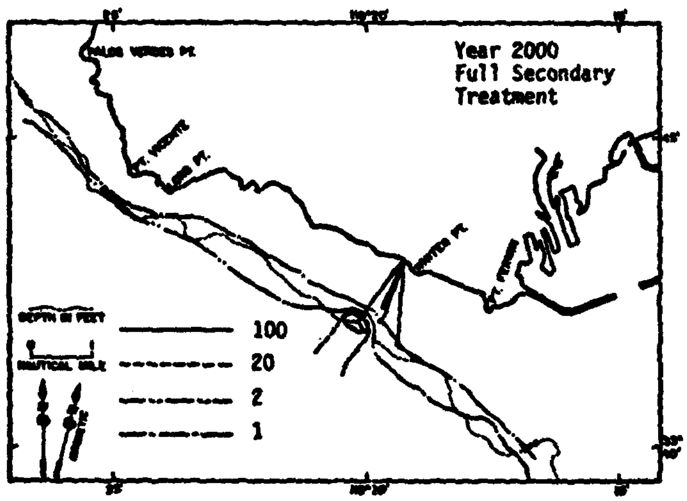


Figure 9. Predicted Year 2000 Concentrations of Total DDT among Palos Verdes Surface Sediments (mg/dry mg). Predictions correspond to Partial and Full Secondary Treatment Scenarios at JWPCP (See Text for Explanation).

Significant improvements in percent coverage and species diversity in the rocky subtidal community are expected to accompany treatment process improvements. Recovery of sessile organisms is expected along all coastal reaches where outfall-related effects are currently observed, and reduced solids loading will encourage juvenile recruitment and growth of attached algal species at greater depths (reflecting light transmission improvements). Included among these species is Macrocystis (giant kelp), which in the distant past (predischarge) dominated the Palos Verdes rocky subtidal environment. Although it is not possible to predict precisely the degree of recovery, it is felt that following implementation of partial secondary treatment characteristics of the rocky subtidal community, including abundance, percent coverage, diversity, and structure, will return to the range of those expected in similar, but unpolluted areas.

Because the causes of fin erosion and liver enlargement are speculative, it is not possible to say with certainty whether or not these diseases will remain prevalent among demersal fishes following implementation of partial secondary treatment. However, if disease incidence is related to the concentrations of specific toxicants (PCB's, DDT, or heavy metals), anomalies in the local community of demersal fishes should respond favorably to reduction in solids emissions and more efficient industrial waste controls.

The environmental responses to the practice of full and partial secondary treatment are predicted to be very similar. Full secondary treatment would result in lower surface sediment concentrations of organic material than would partial secondary treatment and hence a smaller standing crop of benthic invertebrates, particularly molluscs, in areas of greatest residual impact. Furthermore, full secondary treatment would lead to somewhat higher infaunal trophic index values and greater species diversity over portions of the Palos Verdes Shelf than would partial secondary treatment at JWPCP. However, because burial of existing sediments by future discharges is expected to play an important role in reducing surface sediment concentrations of specific trace contaminants, full secondary treatment will probably lead to higher local surface concentrations of most heavy metals and, significantly, total DDT. (Refer to Figures 7 through 9.) Impacts related to the presence of these contaminants among local sediments are likely to be greater with incremental levels of treatment beyond partial secondary. These impacts include elevated tissue concentrations of trace contaminants and exclusion of echinoderms and crustaceans from the local benthic community.

A series of fully empirical quantitative relationships developed by the staffs of the Sanitation Districts and the Southern California Coastal Water Project (SCCWRP) were utilized to project numerical indicators of several biological characteristics following alternative treatment modifications. These include: (1) excess standing

crop among benthic infauna, (2) the extent of sulfide-bearing (anaerobic) surface sediments, (3) the extents of zones of (a) reduced biomass and species diversity and (b) reduced species diversity but normal to elevated biomass among benthic infauna, and (4) extent of rocky subtidal area suitable as kelp habitat. Projections are summarized in Table 1. It is emphasized that these figures represent an extrapolation from sediment data gathered within considerably more polluted environments. Results indicate that either full or partial secondary treatment at JWPCP will essentially eliminate existing zones of depressed biomass and anaerobic conditions among the Palos Verdes sediments. The bottom area suitable as kelp habitat will be essentially the same following either set of treatment plant improvements. However, partial secondary treatment is predicted to result in a greater standing crop of benthic infauna and depressed species diversity over an estimated 11 square kilometers (4.3 sq. mi) of bottom area.

In summary, either partial or full secondary treatment is predicted to result in significant, though incomplete, recovery from existing deficiencies in what might be consided normal, unpolluted communities of both benthic infauna and demersal fishes over portions of the Palos Verdes Shelf. Full recovery is expected within other local biological communities. Where residual anomalies are projected, full secondary treatment is felt to be a more effective means of limiting biological effects related to the rate of deposition of inert or organic solids, while partial secondary treatment may be a preferable means of controlling surface sediment concentrations of trace contaminants and related effects.

Economics of Treatment Alternatives

Capital and operational costs of alternative treatment levels at JWPCP were developed using actual or prorated bids; operating experience; or, when necessary, generalized cost curves.

The following assumptions contributed to the development of component costs:

1. Full secondary treatment consists of 360 mgd biological treatment capacity and sufficient solids processing equipment to adequately digest, dewater, and dispose of all the sludges produced within the plant without resorting to ocean disposal.

2. Partial secondary treatment would provide biological treatment for 200 mgd. Remaining flow at JWPCP would receive advanced primary treatment. Solids processing would include digestion, dewatering, and disposal of all sludge without resorting to ocean disposal.

Table 1

Summary of Present and Projected Biological Deficiencies Among Palos Verdes Shelf Biota (Projections are Based on Application of Empirical Models Relating Biological Parameters to JWPCP Suspended Solids Mass Emission Rates)[a]

Item	Existing Conditions	Partial Secondary[b] Treatment (waiver granted)	Full Secondary[b] Treatment (waiver application denied)
1. Sediment area characterized by both depressed diversity and biomass among benthic infauna (sq. km.)	5	0.5	0.0
2. Sediment area characterized by depressed diversity and normal or elevated biomass among benthic infauna (sq. km.)	80	12	1
3. Standing crop among benthic infauna (integrated across the entire Palos Verdes Shelf) -- units of metric tons	7060	1500	210
4. Areal extent of sulfide-bearing sediments across the Palos Verdes Shelf (sq. km.)	11	...Essentially none...	

Table 1 (cont'd)

Summary of Present and Projected Biological Deficiencies Among Palos Verdes Shelf Biota (Projections are Based on Application of Empirical Models Relating Biological Parameters to JWPCP Suspended Solids Mass Emission Rates)[a]

Item	Existing Conditions	Partial Secondary[b] Treatment (waiver granted)	Full Secondary[b] Treatment (waiver application denied)
5. Areal extent of suitable kelp habitat on the Palos Verdes Shelf (sq. km.)	4.9	5.5	5.7

[a]Area suitable for kelp recruitment is estimated by superimposing the area in which water depth is less than or equal to the depth of 10 percent incident (surface) light level on the historic maximum areal extent of observed kelp coverage. For these purposes, suitable kelp habitat is defined as the intersection of these two areas. Suitable kelp habitat should not be confused with observed or predicted kelp coverage.

[b]Figures shown represent expected values after steady-state conditions are established. Establishment of such conditions will lag effluent quality improvements by a considerable length of time, perhaps 10 years.

3. Sludge disposal will be accomplished via a combination of methods including landfilling, composting, dehydration/incineration. However, all of the waste activated sludge produced (from either partial or full secondary treatment) is assumed to be thickened via dissolved air floatation, anaerobically digested, dewatered via centrifugation, dehydrated and incinerated. In a subsequent section of this paper, sludge disposal through a separate, deep ocean outfall is explored. Naturally, marine disposal of JWPCP sludges would affect the cost figures developed below.

Table 2 is a summary of capital costs associated with partial and full secondary treatment facilities at JWPCP. All figures are in May, 1980, dollars (Los Angeles area ENR Construction Cost Index equals 3620). As indicated the difference in total capital expense between full and partial secondary treatment cases is approximately $120 million.

A summary of estimated annual operating and maintenance costs is provided as Table 3. Figures were based upon information provided within the LA/OMA Final Facilities Plan, extrapolation from current JWPCP operating practice, and relevant cost curves. Costs are in May, 1980, dollars. The estimated differential O&M cost is $7.6 million per year. If the $120 million capital cost difference between treatment alternatives is annualized over a twenty-year period at a discount rate of 7-1/8 percent per annum, the total differential cost attributable to denial of the Sanitation Districts' waiver application is about $19 million per year.

Cost Benefit Analyses of Alternative Treatment Scenarios

It is possible to gauge the merit of a Section 301(h) variance at JWPCP by arranging the information above into an awkward cost benefit comparison. If we assume that there is no danger of reemergence of formerly buried, highly contaminated sediments following implementation of full secondary treatment, model results suggest that benefits of applying federal effluent standards to the Whites Point discharge (i.e., denial of the Districts' waiver application) amount to reestablishment of normal diversity and biomass levels across perhaps 11 sq. km (4.3 sq. mi.) of the Palos Verdes Shelf. The annualized cost of that improvement is estimated at $19 million per year (May, 1980, dollars.)

Sludge Management Alternatives

Background

This section will develop and compare the economic and environmental costs attributable to sludge disposal via (1) the

Table 2

Capital Costs for Partial and Full Secondary Treatment Facilities at JWPCP[a]

CAPITAL COST ITEM	PARTIAL SECONDARY TREATEMENT (waiver approved)	FULL SECONDARY TREATMENT (waiver rejected)
1. Secondary influent pump station & forcemain	12.0	13.5
2. Biological reactors & clarifiers	62.7	112.6
3. Cryogenic plant for pure oxygen generation	13.3	23.9
4. Waste activated sludge dissolved air flotation thickening	3.3	5.9
5. Additional digester capacity	18.2	32.8
6. Centrifuges and station for dewatering waste-activated sludge	11.3	20.7
7. Combined cycle power plant for electricity production from methane.	28.8	28.8
8. Carver-Greenfield sludge dehydration and energy recovery system	68.0	98.2
Total Capital Cost	$217.6 million	$336.4 million

[a]All costs in millions of dollars (May, 1980 - Los Angeles Area ENR CCI = 3620).

Table 3

Annual Cost for Operation and Maintenance of Partial and Full Secondary Treatment Facilities at JWPCP[a]

COST ITEM	PARTIAL SECONDARY TREATMENT (waiver approved)	FULL SECONDARY TREATMENT (waiver denied)
1. Biological Treatment		
a. Energy[b]	4.6	8.3
b. Labor	1.7	2.4
c. Materials & supplies	0.3	0.5
2. Solids Processing & Disposal		
a. Labor	2.7	3.5
b. Polymers	4.1	4.7
c. Carrier oil	0.9	1.5
d. Energy	2.8	3.7
e. Energy credits[c]	-6.8	-7.8
f. Maintenance & supplies	2.4	3.5
Net annual O&M cost[d]	$12.7 million/yr	$20.3 million/yr

[a]All costs in millions of dollars per year (May, 1980 - Los Angeles Area ENR CCI = 3620)

[b]Energy consumption is primarily for generation of pure oxygen.

[c]Both the methane (in digester gas) and dehydrated sludge will be combusted for energy. Energy generated in excess of JWPCP demand will be sold.

[d]It should be noted that items shown do not include all the O&M costs at JWPCP. The only cost items included in the table are those which are sensitive to the capacity of secondary treatment units in operation.

recommended LA/OMA plan—a combination of methods including dehydration/incineration, composting for sale as soil amendment, and landfill disposal, and (2) a deep ocean sludge outfall. Unit process schematics corresponding to each disposal alternative are provided as Figure 10 and Figure 11, respectively. Economic costs and environmental effects related to these and other sludge disposal alternatives were developed in the course of the LA/OMA Project and updated for this paper on the basis of additional information now available.

Several factors related to development of the LA/OMA facilites plan and the plan itself should be emphasized.

Throughout the life of the LA/OMA project, EPA contended that the 1977 Amendments to the Marine Research, Sanctuaries, and Protection Act (MPRSA - P.L. 95-153) prohibited ocean dumping of all municipal wastewater sludges after December 31, 1981. In light of the supposed ban on ocean dumping, it was inconceivable that Congress would deliberately create an alternative avenue, pipeline disposal, for the marine discharge of sludges, and EPA ruled that the Section 301(h) provisions of the Clean Water Act did not apply to the marine discharge of sewage sludges via pipelines. EPA reinforced its assertion by refusing to fund portions of the LA/OMA Project (carried out as a Step 1 grant within the Clean Water Grants Program) which were devoted to the study of marine disposal alternatives. Although local municipalities financed the investigation of several ocean disposal alternatives which lay outside the scope of the federal grant, it is possible that ocean disposal would have received more considered evaluation within the LA/OMA Project had EPA adopted a less intransigent position.

More recently, a federal court ruling has indicated that only sludge disposal activities which produce an unreasonable degree of harm to the marine environment are subject to the impending MPRSA ban. Furthermore, EPA must consider the effects of ocean dumping in relation to the costs of land-based disposal alternatives in reaching conclusions regarding unreasonable harm. A major shift in EPA policy appears imminent, though not yet reflected in published regulations related to disposal of sewage sludges via ocean dumping. Less certain is the status of sludge disposal via deep ocean outfalls such as that which is currently operated by the city of Los Angeles. Sludge outfalls are subject to provisions of the Clean Water Act, and it is not yet clear that reconsideration of the dumping ban imposed under the MPRSA extends to EPA's former statements regarding the legality of pipeline disposal of sludge. It seems reasonable to expect, however, that a single set of criteria will eventually govern the acceptability of marine sludge disposal via any conveyance system.

Energy recovery from sludge incineration is integral to the economic viability of the recommended LA/OMA disposal plan, and efficient evaporation of water from sludges prior to their

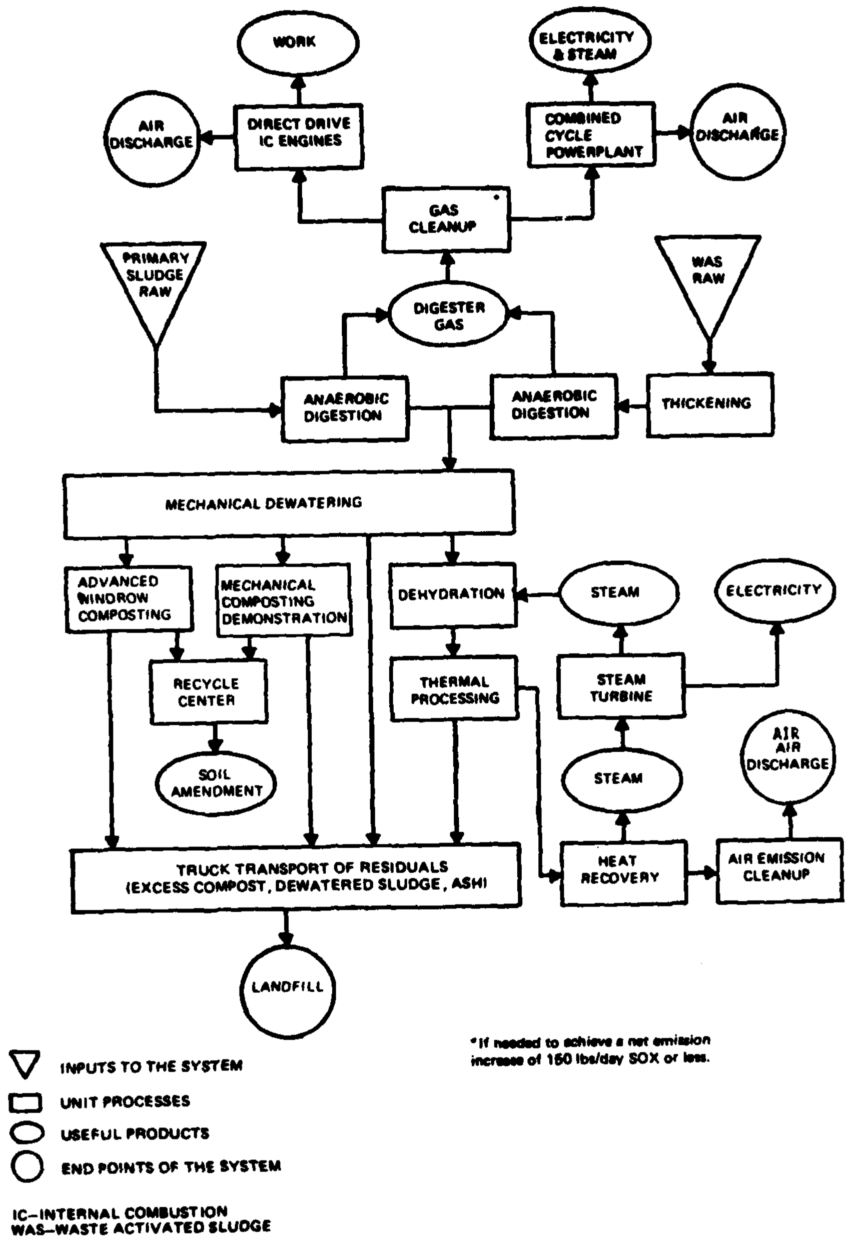


Figure 10. The recommended LA/OMA Plan for Sludge Processing at JWPCP.

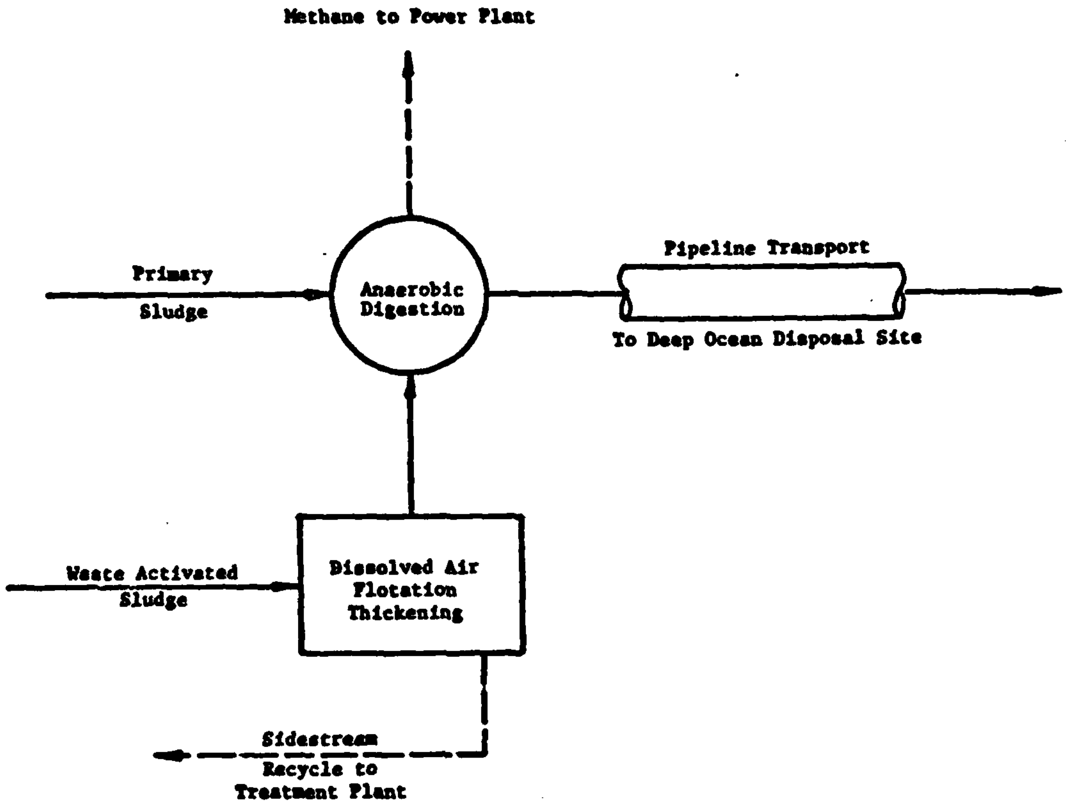


Figure 11. Schematic Representation of Unit Processes Included in Deep Ocean Sludge Disposal Alternative

combustion is critical to net energy production from the overall process. The Carver-Greenfield process is the selected method for dehydration prior to sludge incineration. At this point, it is fair to say that neither the Carver-Greenfield dehydration process nor recommended air emission control measures (necessary to ensure project viability in light of stringent, comprehensive air pollution limitations effective within the Los Angeles Basin) are well established technologies, at least when applied on the scale envisioned. Consequently, cost estimates presented in this paper represent lower limits for expected capital and operating expenses. There remains some question as to whether the recommended system can perform in the manner specified at any cost.

Throughout the development of sludge disposal costs, it was assumed that a waiver of secondary treatment effluent standards will be granted for JWPCP. Waiver denial would aggravate differential cost estimates summarized below.

Description of Recommended LA/OMA Plan[4]

Figure 10 is a schematic representation of the LA/OMA sludge management recommendation for the Sanitation Districts. From examination of the figure, it is evident that three sludge disposal mechanisms are employed in the proposed program. Primary and waste activated sludge (WAS) will be anaerobically digested for stabilization of organics and recovery of methane gas. The digestion system will be sufficiently flexible to permit separate or combined digestion. Anaerobic digestion of sludge will be followed by mechanical dewatering and dewatered sludge split into three trains for subsequent processing and disposal via composting, dehydration/incineration, or landfilling.

Dewatered primary sludge will feed a windrow composting system. WAS will be added only if field tests demonstrate that such addition does not adversely affect the process. Possible system improvements designed to enlarge the sludge composting operation without leading to nuisance potential include mixing of dewatered sludge and recycled compost prior to placement in the compost field, forced aeration of the sludge/compost mixture, improved turning (mixing) devices, and protection from rainfall.

In the second process train, dewatered sludge (a mixture of primary sludge and WAS) will be dehydrated, pelletized, and combusted in an incinerator for energy recovery and volume reduction. Off-gases from incineration will be combusted and passed through a heat recovery system to produce steam. In turn, the steam will be used to drive the dehydration process and generate electricity. Combusted gases will be exhausted to the atmosphere through a state-of-the-art emission clean-up system, and ash from incinerator processing will be

trucked to a sanitary landfill. It is anticipated that an average of 250 dtpd, or about one-half of the projected sludge produced at JWPCP, will be processed and disposed of in this manner.

Truck transport of dewatered sludge for landfill disposal will be used as necessary to accommodate the volume of sludge which cannot be processed by either of the aforementioned processes. Table 4 is a summary of anticipated sludge loadings to each process train.

Environmental Impacts of the Recommended LA/OMA Plan[5]

Potential sources of impact associated with the recommended LA/OMA plan include air emissions from sludge dehydration and combustion, odors associated with sludge composting operations at JWPCP, air emissions from the truck transport of dewatered sludge and thermal processing ash to the landfills, reduction in landfill capacity for solid waste, and landfill leachate problems.

Measures necessary for satisfying state and federal emissions limitations include both: (1) use of advanced, and in some respects marginally established, technology for removal of pollutants from thermal processing flue gas, and (2) reduction of pollutant emissions from other JWPCP sources. On the basis of assumed worst case emission levels and standard modeling techniques, the LA/OMA Project analyses indicated that satisfactory ground level concentrations of selected air pollutants will result from the operation of recommended dehydration/energy recovery facilities.

Due to proposed process design changes, odors and dust emanating from the proposed composting system will be less severe than those currently attributable to composting operations.

Landfill requirements associated with the LA/OMA recommendations may prove burdensome, primarily because of the moisture content (80 percent) of dewatered sludge and acute shortage of local landfill capacity. While dewatered sludge does not require classification as a hazardous waste under the Resource Conservation and Recovery Act, ash from sludge incineration may. In either case, groundwater protection measures remain an important consideration.

In summary, the LA/OMA recommended plan is likely to carry with it additional, though modest, impacts for the already unacceptable Los Angeles Basin air quality. The associated pressure on marginally adequate landfill capacity and aggravation of leachate control problems are potentially more serious impacts.

Table 4

Sludge Loading on LA/OMA Recommended Sludge Processing
and Disposal Facilities
Los Angeles County Sanitation Districts

Year 2000 Primary Sludge Plus 200 MGD WAS from Secondary
Treatment at JWPCP

FEED SLUDGE RATE
(DRY TONS PER DAY)

PROCESS	PRIMARY SLUDGE	WAS	BLEND	REMARKS
Raw Sludge to Anaerobic Digestion	605	130		
Digested Sludge to Mechanical Dewatering	395	100		
Mechanical Dewatering of a Blend of Digested Primary Sludge & Waste Activated Sludge			250	Based on minimum 50-50 blend of PS/WAS. Probable cake solids of 19 percent.
Dehydration			240	
Thermal Processing			240	
Char/Ash Truck to Landfill			90	
Mechanical Dewatering of Digested Primary Sludge	250			
Advanced Windrow Composting	100-150			Sludge loading is expected to vary throughout the year.
Dewatered Cake to Landfill	75-150			Sludge loading is expected to vary throughout the year.

Description of Deep Ocean Sludge Outfall System

The sludge outfall proposed for this analysis is assumed to extend offshore from Whites Point approximately four kilometers and terminate in a multiport diffuser at a depth of about 1,000 feet (300 meters). The diffuser will lie on the relatively steep upper slope of the San Pedro Basin. (See Figure 12.) In addition to the outfall/diffuser system, project components would include dissolved air flotation thickening for waste activated sludge, anaerobic digestion of all sludges generated at JWPCP, and construction of a combined cycle power plant for generation of electrical energy from digester gas. A project schematic is provided in Figure 11.

Environmental Impacts of Deep Ocean (Pipeline) Sludge Disposal

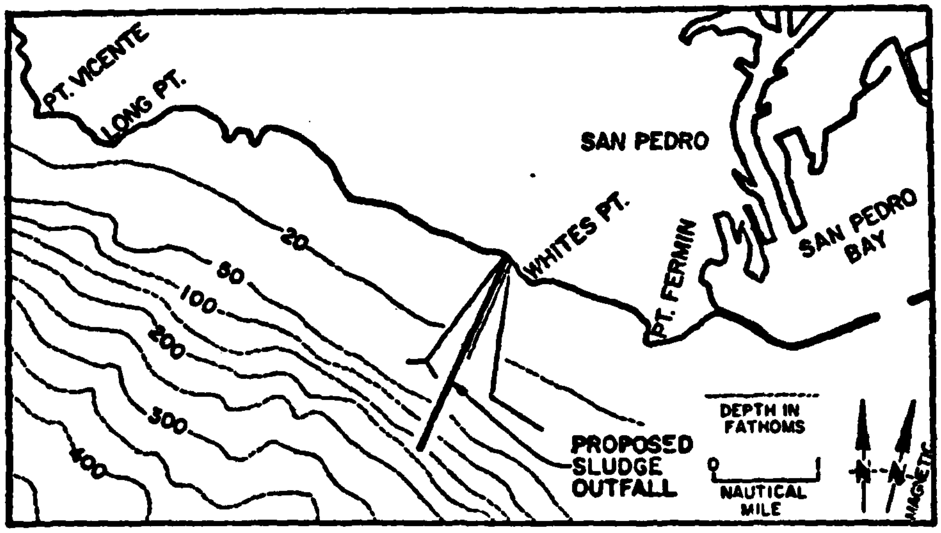
Sources of information. The body of relevant information (data and experience) with which to project environmental impacts attributable to marine sludge disposal off the Palos Verdes coast can be summarized as follows:

1. The Environmental Quality Laboratory (EQL) of the California Institute of Technology evaluated various marine disposal strategies during the development of the LA/OMA Sludge Management Plan. Their effort resulted in a report which assesses the relative merit of sludge discharge at several depths within the Santa Monica and San Pedro Basins.[6] This material represents the most direct scientific effort conducted to date to estimate the environmental consequences of such activity. The EQL assessment was based in part on biological information collected in several deep basin trawls and sediment grabs carried out by the Southern California Coastal Water Research Project.

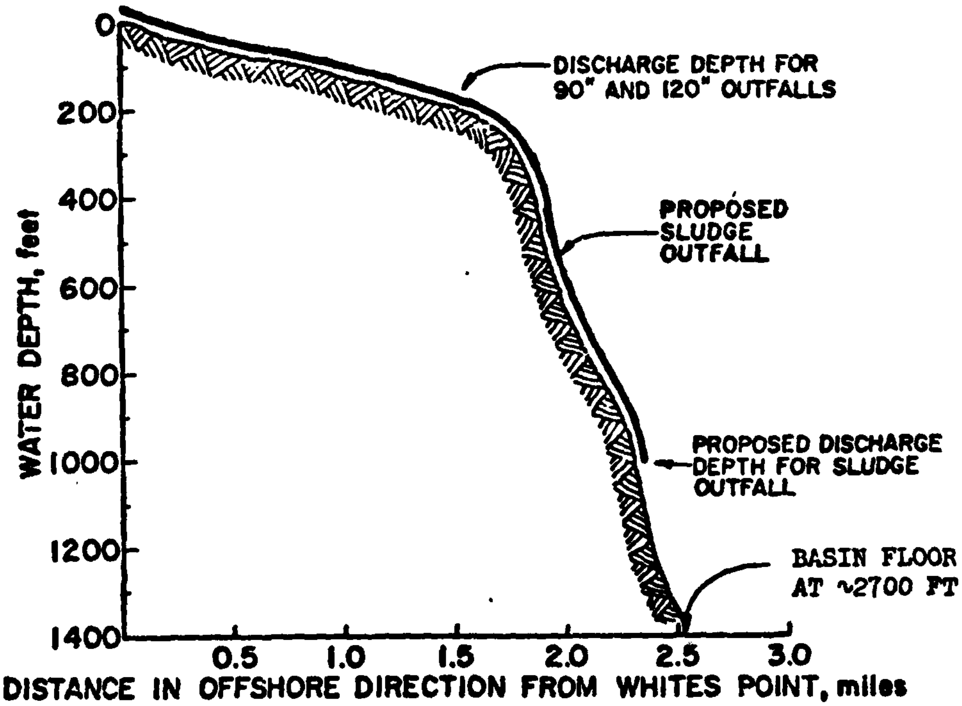
2. In 1972 and 1973, a series of oceanographic cruises sponsored in part by the University of Washington were conducted in Southern California waters and points south. Resultant data include measurement of physical parameters (temperature, density stratification, etc.) among waters of San Pedro Basin.[7, 8]

3. Over a period of several years, SCCWRP has collected oceanographic data which are of some utility in describing existing biological communities at the proposed sludge discharge depths (300 to 800 meters) and predicting outfall-related effects following development of a deep ocean sludge disposal alternative.[3, 9, 10]

4. The LA/OMA Project Final Environmental Impact Statement (EIS)/Environmental Impact Report (EIR) (State of California equivalent of EIS) contains descriptions of both existing biological conditions in potential deep ocean disposal sites and probable impacts associated with marine sludge disposal options.[5]



PLAN



PROFILE

Figure 12. Candidate Alignment for JWPCP Sludge Outfall

5. The most direct, physical evidence of outfall-related effects is provided by the city of Los Angeles' seven-mile sludge outfall. For almost 25 years, the city has discharged sludge from the Hyperion Wastewater Treatment Plant at a point near the head end of the Santa Monica Canyon (100-meter depth). Scientists from both SCCWRP and the California Institute of Technology have studied physicochemical and biological effects attributable to this discharge. However, extrapolation from these observations to basin sites proposed for the discharge of JWPCP sludges is handicapped by significant depth, topographic, and perhaps other site-specific differences.[10, 11]

6. As indicated earlier in this report, discharge-related impacts on the Palos Verdes Shelf are directly related to JWPCP solids emissions. Consequently, the Sanitation Districts' experience in marine wastewater disposal may be of some benefit in predicting outfall-related effects attributable to sludge discharge to deeper waters.[6]

Description of existing physical conditions. In order to estimate the probable consequences of the marine sludge disposal option, it is necessary to appreciate various physical and biological features of the marine environment in the vicinity of the proposed sludge discharge. At a depth of 300-meters, the slope to the San Pedro Basin is relatively steep, considerably steeper than the Palos Verdes Shelf area in the vicinity of the existing JWPCP discharge sites, as shown in Figures 12 and 13. As a result, the 300-meter depth contour lies only about four kilometers (2.5 miles) off Whites Point and can be reached with a relatively short outfall.

The topography of the ocean floor off Los Angeles and Orange Counties restricts the exchange of San Pedro Basin water with that of the open ocean. The rate of water exchange and, as a consequence, dissolved oxygen concentration decrease significantly with depth. Oxygen-demanding organic debris, which rains on the basin continuously, contribute to the characteristic reduction of dissolved oxygen with depth. A typical dissolved oxygen profile for waters of the San Pedro Basin is provided as Figure 14. Below 200 to 300 meters, demersal fish abundance, biomass, and numbers of species decrease with decreasing dissolved oxygen and temperature.

Little is known about current patterns among deep basin waters. Based on current measurements in Santa Monica Canyon and on the Palos Verdes Shelf, it is felt that currents at the 300-meter depth will be considerably weaker than those which characterize the shallower existing wastewater discharge sites. Furthermore, the well-defined slope to the San Pedro Basin should produce currents that are generally parallel to depth contours. However, because

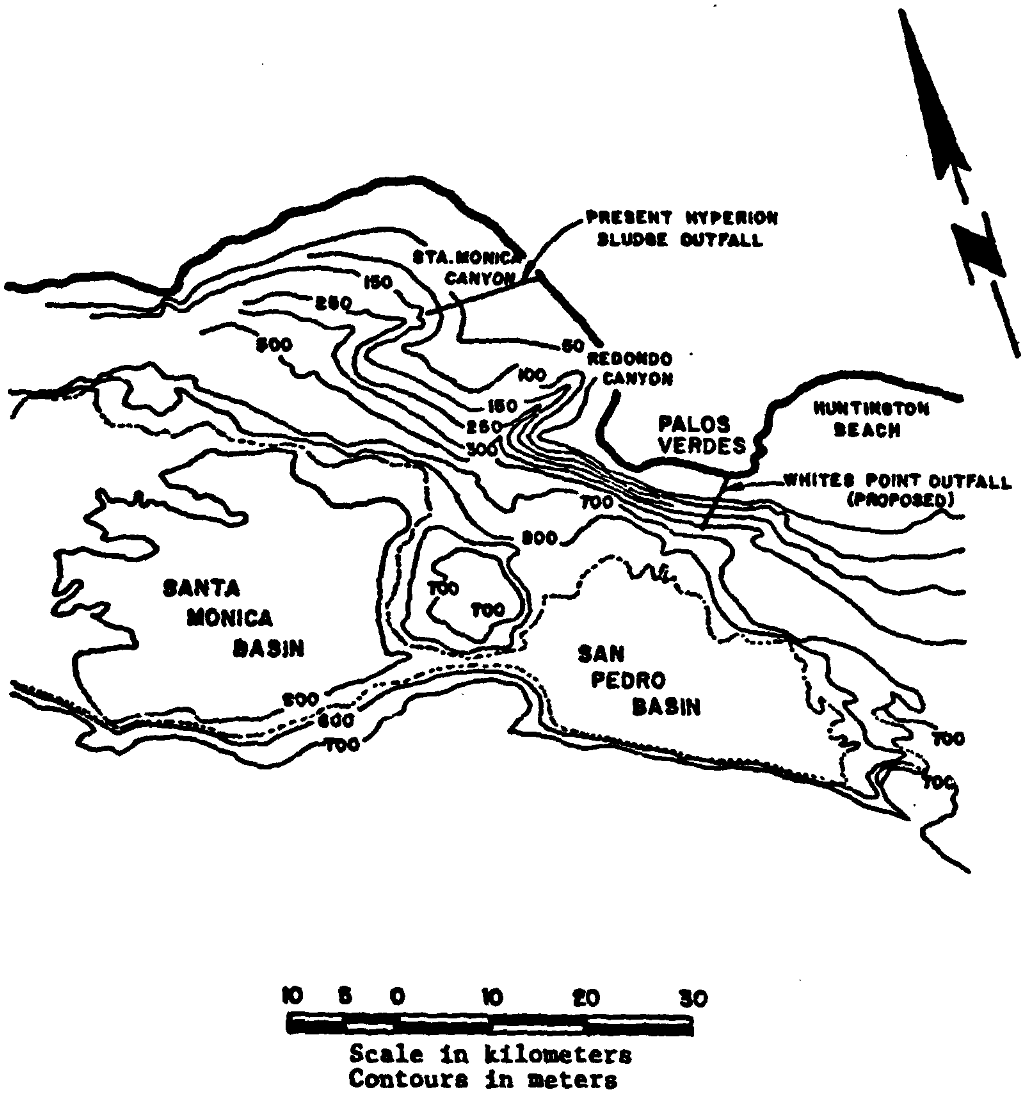


Figure 13. Basin Bathymetry off the Southern California Coast - San Pedro and Santa Monica Basins

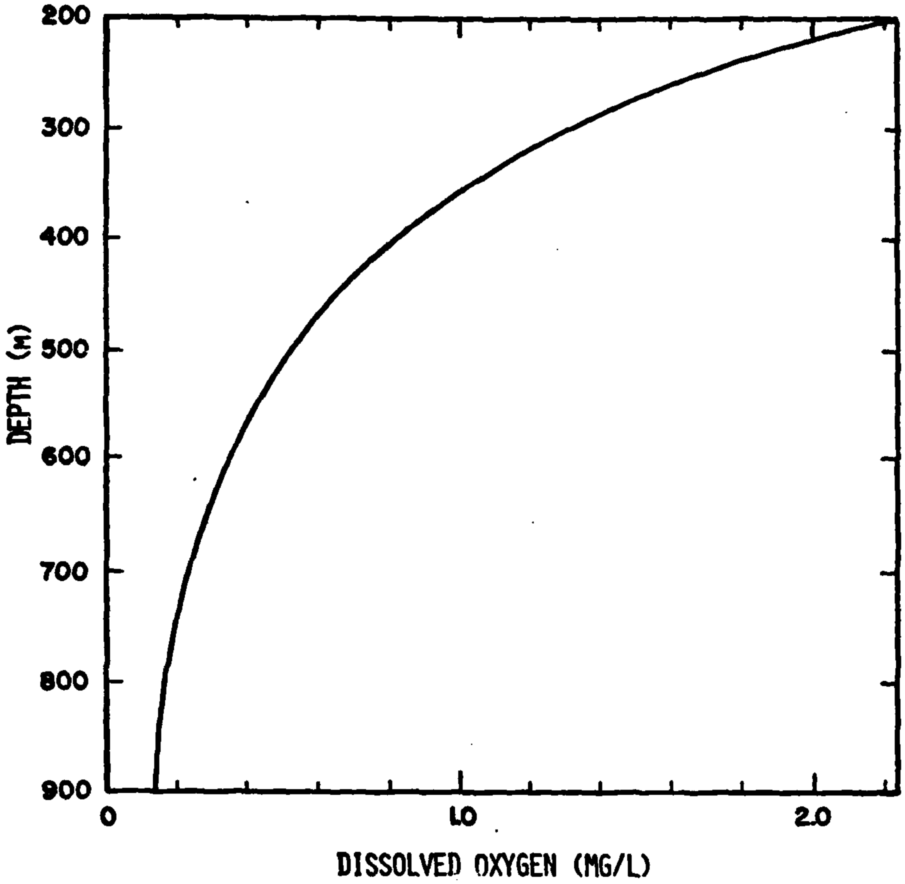


Figure 14. Typical Dissolved Oxygen Profile within the San Pedro Basin off the Palos Verdes Coast

current patterns will impact the dispersal of discharge-related contaminants among basin sediments and in the water column, a detailed current survey is recommended as part of any outfall siting procedure.

Density stratification among deep basin waters above the 300-meter depth is an important consideration from the standpoint of pollutant transport. Although limited, available temperature and density data in the vicinity of the 300-meter depth of the San Pedro Basin are remarkably uniform (temperature variations betweem 8.0 and 8.5°C and between 26.6 and 26.7). On the basis of initial dilution and height of rise calculations carried out relative to the Whites Point outfalls, it is felt that stratification among deep ocean waters is more than sufficient to trap the sludge discharge wastefield at depths that ensure its isolation from surface and nearshore waters of the Palos Verdes Shelf. Thus deepwater sludge discharge would in no way impact nearshore water clarity or the extent of suitable kelp habitat. (See previous discussion.) Nearshore and shoreline bacteriological quality would also be unaffected by such activity. Decreases in water clarity at 300 meters would not limit primary productivity due to the lack of available light under normal conditions. However, because plume trapping level, initial dilution, plume rise, etc., are functions of such variables as sludge density, diffuser design, etc., and because available oceanographic data do not yet provide a reliable physical picture of potential sludge discharge sites, additional deepwater monitoring is strongly recommended prior to outfall site selection.

Description of existing biological conditions. The most useful indications of baseline biological conditions at the proposed San Pedro Basin sludge disposal site are provided by deepwater biological samples (trawls and benthic grabs) taken and analyzed by SCCWRP scientists. Numerous benthic samples were taken along the 300-meter depth contour and subsequently characterized in terms of invertebrate biomass and infaunal tropic index (ITI). During the last two years, SCCWRP has striven to extend its ITI survey to depths approaching 800 meters. On the basis of such measurements and calculated indices, it is evident that the upper slope of the San Pedro Basin is not a pristine area owing to its proximity to the Whites Point wastewater outfalls. Impacts are evident in the forms of elevated biomass and local depression in ITI relative to control stations. Few juvenile demersal fish were found in deepwater trawls, and fin erosion was observed among Dover sole taken from Palos Verdes transect stations to a depth of 460 meters. The disease grew less prevalent with increasing depth (and distance from the Whites Point outfall). Trawl data also indicated a moderate decline in number of species, and thus species diversity, among benthic invertebrates taken below the 200-meter depth contour.

Although deep-water trawls throughout the Southern California Bight indicate that the invertebrate community is generally dominated by a few species of echinoderms, trawl data from Palos Verdes reveal a local paucity of echinoderms. The suspected cause of their disappearance is the discharge of DDT from the Whites Point outfall system in the years prior to imposition of a ban (1970) on industrial discharges of DDT to the Joint Outfall System. The conservative nature of DDT and its metabolites has prevented the resettlement of echinoderms among the local benthos. The observed depression in echinoderm abundance extends at least to the 610-meter depth about five kilometers from the Whites Point discharge sites. The anomaly grows less severe with increasing depth and distance from the discharge site.

In summary, available data yield the following picture of physical and biological conditions among waters and sediments which would receive JWPCP sludge: Bottom dissolved oxygen, temperature, benthic biomass, and abundance of demersal fish decrease fairly rapidly with depth below 200 meters. Deeper waters appear to present a somewhat more hostile, and perhaps more fragile, environment than does the relatively narrow shelf. Off the Palos Verdes Shelf, the effects of the Whites Point outfall system are discernible on the bottom to at least 610 meters in the form of excess standing crop of benthic invertebrates, decreased echinoderm biomass, and depressed ITI. These effects are variously related to the locally elevated flux of biodegradable material to the ocean floor or the presence of effluent related toxicants among local sediments.

<u>Marine impacts related to the Hyperion Sludge Discharge</u>. Since 1957 the city of Los Angeles has operated the seven-mile sludge outfall, which discharges just beyond the head end of the Santa Monica submarine canyon at a depth of about 100 meters. The canyon was selected as a disposal site because of its relative proximity to the Hyperion Wastewater Treatment Plant and because its relatively steep sides and slope were likely to channel sludge solids further offshore. Benthic sampling programs conducted by both the city and SCCWRP indicate that local sludge accumulation is largely confined to the canyon, although it has been estimated that only about 10 percent of all solids discharged can now be accounted for on the canyon floor. The remainder was either transported out of the region or consumed locally by sea life. The area of heaviest sludge-related deposition is near the head of the canyon. Volatile solids represent over 33 percent of sediment dry weight in that area and are in excess of 10 percent over a rather sizable region, generally down canyon from the discharge point. The relatively firm sandy sediments found inshore of the canyon become very soft within the canyon.

Discharge-related biological impacts are observed within and in the vicinity of Santa Monica Canyon. In the upper canyon, infaunal trophic index values are greatly depressed, indicative of substantial

biological impact within the benthic community. In this area, the number of species and (consequently) species diversity are greatly reduced. Over a considerably larger area, the sludge discharge has stimulated invertebrate productivity, as indicated by excess standing crop and greater numbers of individuals, at the expense of diversity. Trawl results indicate that within the canyon there are more species of demersal fish and more biomass than at control stations. The effect of sludge nutrients on local primary productivity is not clear, probably because discharged material is generally trapped below the euphotic zone and periodic upwelling of naturally enriched water overshadows other effects. Although a specific cause has not been identified, it seems clear that the abnormally high incidence of fin erosion observed among Dover sole taken in the Santa Monica Canyon is related to the local discharge of sludge.

Over the years of sludge discharge, heavy metals and other potential toxicants have accumulated among canyon sediments and local invertebrates. Among the heavy metals monitored, however, only mercury has been observed to accumulate in the muscle tissue of fish which feed on the benthic infauna. Demersal fish do accumulate polychlorinated biphenyls (PCB's), although at levels which are generally below FDA limits for commercially marketable fish. Finally, bioassays conducted using samples representative of sludge outfall effluent quality indicate that sea urchin fertilization and embryonic development are affected detrimentally at dilutions from 600:1 to 1,000:1.

Predicted impacts of the deepwater sludge outfall. On the basis of information and analysis described above, implementation of the deep ocean (pipeline) sludge disposal alternative is expected to impact the local marine environment in the manner described below.

- Benthic environment. Physical effects on the bottom in the vicinity of a deep ocean sludge outfall should be similar in scope to those currently observed in the vicinities of the Whites Point wastewater outfalls and the city of Los Angeles' sludge outfall. That is, the flux of outfall-related organics to the sediments will produce a surface anaerobic zone of unknown dimension in which all indicators of biological quality (abundance, biomass, species diversity, ITI, etc.) will be depressed. In all likelihood, this area will cover no more than a few square kilometers, but its extent will depend heavily upon factors that are not well established, such as particulate settling velocity, current pattern, rates of oxygen demand and supply, diffuser characteristics, etc. Surrounding the anaerobic zone will be a much larger region, also emanating from the discharge point, in which benthic biomass and abundance are elevated above background levels at a cost of lower species diversity. It is conceivable that such a zone could encompass 100 sq. km. of ocean bottom extending primarily in the offshore

and downcurrent directions. In this region, the calculated ITI will lie between 30 and 60. Heavy metals and other potential toxicants of sludge origin will be concentrated among the sediments and local benthic infauna over a fairly large area with the highest values concentrated in the vicinity of the outfall. Heavy metals will not be biomagnified, but PCB's and other synthetic organics are known to be concentrated in fish tissue. For this reason, industrial waste source control and related monitoring will be an important part of any deep ocean sludge disposal program. Remaining echinoderms and perhaps other taxa such as crustaceans are likely to be replaced by more pollution tolerant species in the outfall vicinity.

o <u>Demersal fishes</u>. It is likely that the incidence of fin erosion will increase significantly among deepwater Dover sole and perhaps one or two other species of fish within the San Pedro Basin in response to the proposed sludge discharge. Likewise, liver enlargement, which has been attributed to wastewater discharges, will become more prevalent. Muscle and especially liver tissue concentrations of PCB's and other synthetic organic chemicals will increase among demersal fish. Where standards exist, FDA limits for marketable fish may be exceeded in some edible tissues. The associated risk to humans is negligible because the bottom waters of the San Pedro Basin are not regularly fished commercially or for recreation. The abundance, biomass, and numbers of species of demersal fish will probably increase in the outfall vicinity due to the availability of a more abundant food source.

o <u>Midwater community</u>. Potential water column effects of deep water sludge disposal include oxygen depletion below levels necessary to sustain the existing midwater community, reduction in water clarity, and elevation of water column concentrations of potential toxicants, such as heavy metals and synthetic organics. Midwater predictions developed by EQL indicate that, subject to conditions imposed on the analysis, sludge disposal at 400 meters or less will not result in either deleterious water column dissolved oxygen depletion or metals concentrations in excess of limits established within the California State Ocean Plan.[6] Associated reductions in water clarity should be of limited biological significance inasmuch as the discharge will be trapped below the euphotic depth.

In summary, the scope of expected environmental impacts is similar, though not equivalent, to those attributable to existing outfalls in the Santa Monica Canyon and on the Palos Verdes Shelf. Due to site specific topographic considerations, sludge-related effects in the San Pedro Basin would be expressed over a greater area but less severe in form than those currently observed in Santa Monica Canyon. There are other important physical differences

between the basin setting and either the Santa Monica Canyon or Palos Verdes Shelf. Differences between current patterns, dissolved oxygen concentrations, and temperatures affect the relative abilities of these environments to assimilate wastes without triggering odious biological changes. Unfortunately, the implications of physical differences among these environments are not well understood, and restraint should be practiced in extrapolating from experience gained in a single physical setting.

The principal advantages of deep basin disposal relative to the Palos Verdes Shelf lie in (1) the relative isolation of basin waters and consequent lack of nearshore and health-related effects, and (2) the reduction in biological activity which is characteristically observed with increasing depth--there simply are fewer creatures present to be affected.

Economic Comparison of Sludge Disposal Alternatives

As indicated in Table 5, the estimated capital cost of recommended LA/OMA sludge processing facilities is almost $150 million (May, 1980, dollars). Per Table 6, the annual cost for operation and maintenance of recommended facilities is estimated at $9.1 million. This figure includes a credit for electrical power that is produced by sludge incineration, but consumed in other treatment processes at JWPCP.

Capital and operational costs for the marine disposal option, also provided in Tables 5 and 6 are sensitive to discharge site selection. It was assumed that the Sanitation Districts' sludge outfall would extend approximately four kilometers offshore from Whites Point and terminate at a depth of about 300 meters on the slope leading to the San Pedro Basin. Anaerobically digested sludge would be screened prior to discharge and screenings trucked to sanitary landfills.

The estimated capital cost of a deep ocean sludge outfall system is $80 million and the total annual operation and maintenance cost is $4.5 million per year. However, the value of electricity produced from digester gas is placed at $5.9 million per year; net benefits of about $1.4 million per year should result from sludge processing and disposal operations under the ocean disposal alternative.

Comparison of cost estimates corresponding to alternative sludge management plans indicates that a capital cost increment of $68 million and an additional operation and maintenance cost of $10.5 million would be attributable to selection of the LA/OMA recommendation. The total annualized cost difference is $17 million per year (all figures in May, 1980, dollars).

Table 5

Capital Costs of the Recommended LA/OMA Plan and Ocean Pipeline for Disposal of JWPCP Sludges[a]

CAPITAL COST ITEM	RECOMMENDED LA/OMA PLAN	OCEAN OUTFALL DISPOSAL
1. Dissolved air flotation thickening	3.3	3.3
2. Additional digestion capacity	18.2	18.2
3. Combined cycle power plant[b]	28.8	28.8
4. Mechanical dewatering (centrifugation)	11.3	-
5. Wet cake storage	5.8	-
6. Sludge dehydration/incineration[c]	68.0	-
7. Char/ash trucking	0.5	-
8. Wet cake trucking	1.0	-
9. Advanced windrow composting[d]	11.1	-
10. Sludge outfall, pumping station, etc.	-	30
TOTALS	$148.0 million	$80.3 million

[a]All costs in millions of dollars (May, 1980 - Los Angeles Area ENR CCI = 3620)

[b]The combined cycle power plant will be used to generate useable electrical energy from the combustion of methane, a product of anaerobic sludge digestion.

[c]Includes costs of air emissions control equipment and credit for electrical energy produced from sludge combustion.

[d]Costs are for recommended modifications to existing composting facilities.

[e]The authors provide this estimate with little confidence. Cost estimates by others[4, 6] offer widely disparate figures for this construction.

Table 6

Estimated Annual Costs for Operation and Maintenance of Alternative JWPCP Sludge Disposal Systems[a]

Cost Item	LA/OMA Selected Plan	Deep Water Outfall Disposal
1. Labor	4.1	2.4
2. Polymer[b]	4.1	0.4
3. Carrier oil[c]	0.9	-
4. Energy costs	3.1	1.3
5. Energy credits[d]	-6.8	-5.9
6. Maintenance & supplies	2.6	0.4
7. Landfill charge	1.1	-
TOTALS	$9.1 million/yr	-$1.4 million/yr

[a]All costs in millions of dollars per year (May, 1980, Los Angeles Area ENR CCI = 3620)

[b]Polymer is utilized to improve process performance during DAF thickening and centrifugation.

[c]Necessary to maintain fluid properties of dehydrated sludge prior to pelletization.

[d]Energy credits are attributable to operation of the combined cycle power plant and sludge incineration units.

Risks

There are uncertainties associated with either sludge disposal alternative described in this paper. The LA/OMA Project recommendation is based upon application of advanced technology for both (1) dehydration of dewatered sludge, and (2) mitigation of potential air quality impacts related to combustion of the dewatered product. To date, the Carver-Greenfield dehydration process has been used successfully to dehydrate primarily organic industrial sludges and, although the LA/OMA staff took great pains to evaluate its feasibility in municipal wastewater applications, implementation of the system on the scale envisioned represents a substantial financial risk.[12, 13] Likewise, the recommended air emissions cleanup system qualifies as state-of-the-art technology and will provide challenging construction and operational problems.

Uncertainties related to pipeline disposal in the marine environment are not particularly well defined, primarily because no comprehensive oceanographic monitoring program has been conducted within the deep ocean basins. The EQL report on sludge disposal (see above) indicates that an outfall at either 600 or 800 meters would lead to basinwide oxygen depletion (below the discharge depth) with grave consequences for the inhabitants of those regions. Discharge at 400 meters, however, is predicted to result in acceptable oxygen depression throughout the basin, primarily due to the presence of higher dissolved oxygen concentrations. It is unlikely that available oceanographic data provide an adequate foundation on which to premise the level of detail reflected in the conclusions of the EQL report. Additional information should be gathered relative to deep-water density stratification, current patterns, sludge settling characteristics following initial dilution with seawater, and oxygen transport and utilization kinetics. Similarly, additional predischarge biological monitoring is advisable in the vicinity of a proposed deepwater outfall.

Recommendations

Based on the information and analysis contained in this paper, the following actions related to waste discharge into the marine environment are recommended.

1. The sanitation districts believe that a waiver of full secondary treatment requirements at JWPCP under Section 301(h) of the Clean Water Act is appropriate. Potential savings in capital and operational expenses justify evaluation of the response of the marine environment to partial secondary treatment practice prior to implementation of any higher form of treatment. A comprehensive monitoring program should accompany waiver application approval. That program

should lead to quantification of discharge-related environmental changes and development of rational cause-effect relationships among effluent quality, selected physical oceanographic characteristics (water clarity, sediment redox conditions, etc.), and indicators of biological well-being.

2. Should a majority of the municipalities discharging to waters of the Southern California Bight qualify for 301(h) variances, a regional monitoring program should be implemented in which data-gathering techniques, sampling frequencies, and data analysis are standardized. In the long term, regional monitoring would provide a series of bightwide snapshots of environmental conditions and permit analysis of larger scale, time-dependent changes in marine environmental health.

3. It should be recognized that the five-year evaluation period which accompanies a waiver approval will not provide adequate information with which to test the merit of waiver renewal at JWPCP. Process improvements which comprise partial secondary treatment will not be completed within five years, and benthic response to improved treatment is not expected to be rapid. It is recommended that EPA approve all 301(h) applications submitted by deep ocean dischargers within the Southern California Bight for a 10-year period.

4. The sanitation districts believe that implementation of the recommended LA/OMA sludge disposal plan should await assurances that (1) potential technical problems associated with full-scale sludge dehydration and energy recovery operations can be overcome at a reasonable cost, and (2) there is, in fact, sufficient environmental justification for avoiding deep ocean pipeline disposal of sludge. The following steps should be taken by Southern California municipalities before large, irreversible, financial commitments for sludge disposal facilities are made:

(i) A 100 dry-ton-per-day (dtpd) capacity dehydration/energy recovery system should be constructed and operated over a representative period. This large-scale test should not conclude until sufficient evidence has been gathered to demonstrate the technical and economic feasibility of component processes including air emission control measures. Reliable cost and energy use/recovery information should be among the resultant data.

(ii) A large-scale, deep basin sludge outfall should be built and operated for perhaps 10 years. The project should be preceded by a rigorous oceanographic survey of potential discharge sites in order to select an appropriate site and provide baseline environmental data with which to assess the physical and biological impacts of deep basin disposal. An equally rigorous ocean monitoring program should be carried out while the test is in progress in order to anticipate irreversible environmental damages or potential health effects. The municipality

which participates in this program should guarantee that it will rapidly convert to alternative sludge disposal methods if it becomes apparent that deep ocean pipeline disposal is ill-advised.

(iii) A large-scale (100 dtpd) deep ocean barge disposal program aimed at developing economic and environmental costs associated with such a disposal method should be undertaken. Once again, baseline and follow-up ocean monitoring would play an essential role.

(iv) Following development of an adequate data base or when 10 years have elapsed from the date on which federal, state, and local officials agree to the test (whichever occurs sooner), a preferred, long-term sludge disposal program should be selected and implemented.

(v) The federal government should share in the expense of this set of concurrent tests to the same extent that it bears the costs of sludge disposal in other parts of the country.

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ENGINEERING SYSTEMS FOR WASTE DISPOSAL TO THE OCEAN

by

Norman H. Brooks*

Marine Waste Disposal as an Engineering System

Successful waste water and sludge disposal in the ocean depends on designing an appropriate engineered system where the input is the waste and the output is the final water quality which is achieved in the vicinity of the disposal site. For municipal sewerage systems, the principal variable components are:

- source control (or pretreatment) of industrial wastes before discharge into municipal sewers;

- sewage treatment plants, including facilities for processing of sewage solids (sludge);

- outfall pipes and diffusers for disposal of effluents into the ocean, and either barges or pipelines for disposal of sewage sludge.

There are important trade-offs between these three components of a system. Until now, regulatory policies have tended to give little recognition to outfall technology and have concentrated largely on sewage treatment at central plants and source control. However, Section 301(h) of the 1977 amendments of the Federal Water Pollution Control Act was an important change which allows an ocean discharger to apply, under certain conditions, for a waiver from the mandatory secondary treatment requirement.

Regulations which set ambient water quality standards, rather than effluent standards, allow the most cost-effective system to be designed. On the other hand, if a certain technology is specified, e.g., secondary treatment, then there is no incentive for devising cost-effective high dilution outfall systems.

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Engineering Design of Sewer Outfalls for Effluent

The design procedure for an ocean outfall with a diffuser for effluent discharge is depicted in Figure 1. Inputs (the top boxes in the figure) include:

(1) The water quality objectives and requirements which are set forth by the regulatory authorities and/or the discharge agency.

(2) The environmental factors of the proposed site including a full range of physical, chemical, and biological data gathered over at least a year's time. This information defines not only the environment in which the plume mixing and dispersion occur but also the undisturbed pre-discharge condition. The plume behavior is strongly affected by density stratification and currents. For the structural engineering design, it is also necessary to have a detailed bathymetric map, information on the wave environment, and geotechnical investigations of foundation conditions.

(3) The effluent quality and flow rates. The quality is determined by the degree of treatment, e.g., primary or secondary, and the degree of control of trace contaminants at their sources (or pretreatment). The buoyancy of the effluent relative to seawater is also important in the dynamics of the plumes.

With these inputs, a trial outfall design may be developed by procedures described elsewhere.[1, 2, 3] The site of the outfall is dictated by both nearfield and farfield requirements, while the diffuser length and port details are primarily based on the nearfield dilution and submergence objectives. The fluid dynamics of initial dilution calculations is well in hand, as is the hydraulic design of large diffusion structures. While experience with outfall designs has been very good on the West Coast, there are still important research needs for more detailed after-the-fact analyses of outfall performance, both nearfield and farfield.

With a trial design, both the nearfield and farfield water quality can be predicted in detail for the full range of the variable environmental parameters and flows for comparison with objectives. These predictions have frequency distributions in response to the temporal variations in the inputs (currents, stratification, flow). If the objectives are not met, or the optimum system is not obtained, then the system is adjusted by changing the treatment (or pretreatment) and/or the physical location and design of the outfall. (A reasonable margin of safety should be allowed to accommodate uncertainties and errors in the predictions.) Occasionally, the water quality objectives

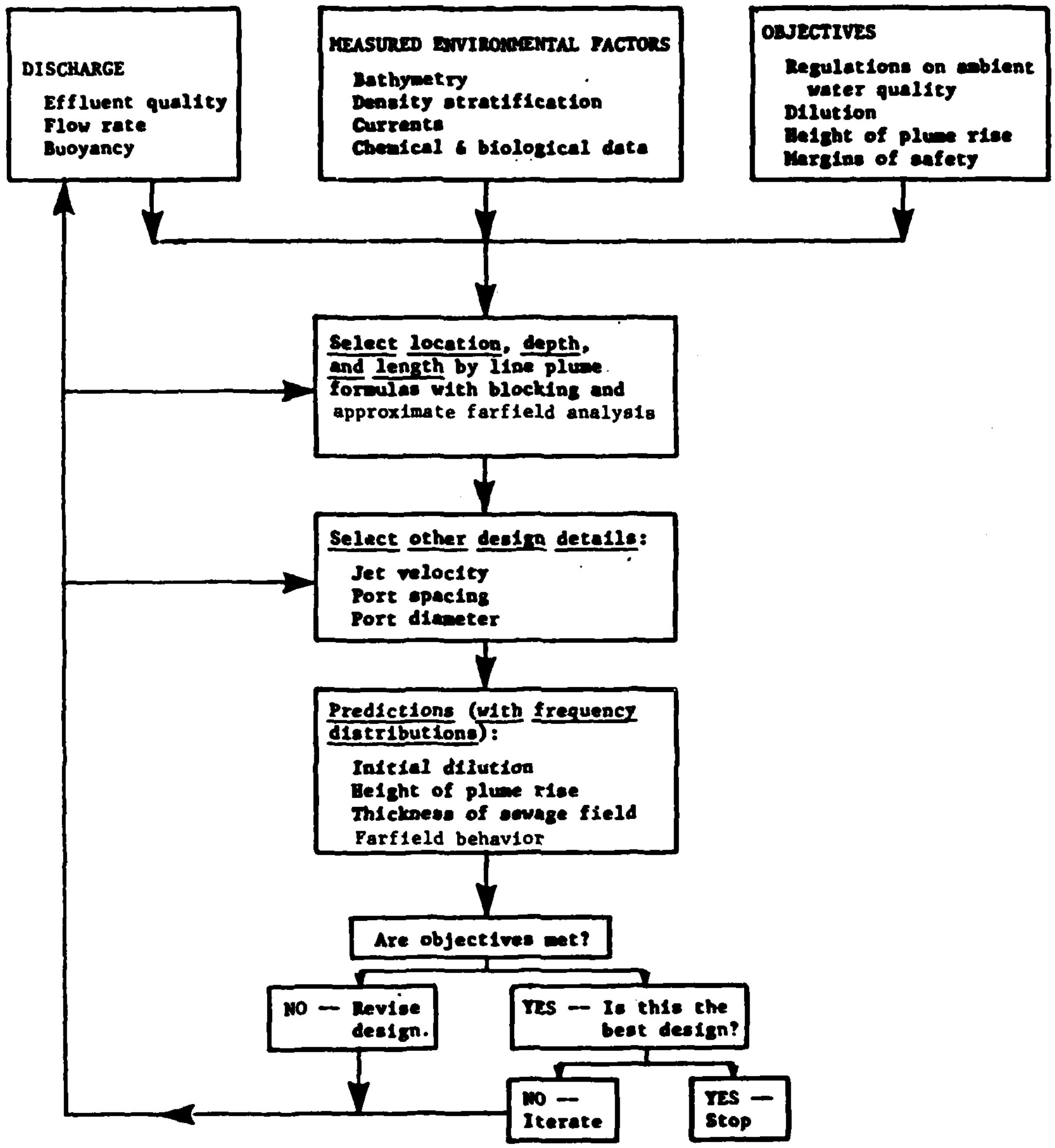

Figure 1. Design Procedure for Sewage Outfall with Diffuser

will also be modified if the cost of achieving them is exorbitant compared to the water quality benefits to be achieved. It is this overall systems view that is not captured in federal regulations.

In a sense, we are starting with the objectives and working "backwards" to design a system which will be the optimal way to achieve them. The resulting system usually will involve certain trade-offs. For example, if a longer, deeper outfall is selected, then less treatment is needed (see Appendix A, Table 1). If trace contaminants cause problems, they need to be solved at the sources, because with more advanced treatment at the municipal plant more trace contaminants are caught in the sludge which will still have to go somewhere.

Apart from the current regulatory constraints, the top priority technical problems for wastewater disposal in the ocean are the control of emissions of trace contaminants to safe levels, and the avoidance of excessive concentrations of sewage particles either in the water column or accumulating on the bottom. Removal of BOD (biochemical oxygen demand) by secondary treatment is usually not a priority problem, in contrast to many freshwater disposal situations. Trace contaminants can probably best be controlled at the sources (rather than by sewage treatment), while particles are primarily removed by sedimentation, which is sometimes enhanced by additions of polymers or other flocculating agents.

To me, the term "assimilative capacity" is not a useful concept because it tends to imply that up to a certain point, everything is fine, and then beyond that point, things are bad. Instead, it should be understood that any wastewater discharge in the ocean always has some effects (even if small), which depend on the system design as described above. When ocean disposal is used, however, these effects are believed to be much less than the effects of other possible engineering solutions of wastewater disposal, such as to land or inland waters.

Sludge Disposal

Digested sludge disposal to the ocean may be accomplished either by barges or by special sludge outfall pipes. Although federal laws essentially ban ocean dumping of sludge after 1981, there appears to be a lack of scientific or engineering bases for such outright bans. There is a range of possible ways to design the discharge operations, e.g., different depths or distances from shore, and different techniques of dispersal or containment. Recent advances have been made in predictive modeling for the effects of sludge disposal in the ocean[4] and within the next decade we should have a well-established

methodology. The ocean disposal option for digested sewage sludge could then be compared on a more rational basis with other alternatives which impact freshwater, land or air resources.

There is an urgent need for more experimentation on methods of disposing of sludge in the ocean through appropriate research and demonstration projects. One such project has been proposed by the Orange County Sanitation Districts, California (see Appendix A, Table 2).

Conclusion

While considerable progress has been made in developing design procedures for outfalls and barging systems, additional field research would lead to further advances in our knowledge and engineering capabilities. Furthermore, if the ocean disposal option is kept open for both sewage effluent and sludge, with appropriate flexibility for case-by-case evaluations and comparison with air, land, and freshwater options, then more effective overall management of wastewater disposal can be achieved.

In the design of an ocean disposal system, there are always uncertainties and risks due to incomplete knowledge of the marine environment and uncertainties in the predictions of performance. Whenever possible, it is wise to follow a course of action that permits some adjustments as we learn more and gain operating experience with a particular discharge. Feedback is essential!

Appendix A, which is a hearing statement by Brooks and Krier, discusses the policy issues in the light of current regulations, the engineering state-of-the-art, and current knowledge about fates and effects of ocean discharges. It is based on the concluding chapter in a book to be published by the MIT Sea Grant Program.[5]

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DISCUSSION

CSANADY: One comment, Norm, about these toxics that you mentioned, and the heavy metals which you say should be controlled at the source. That certainly applies to municipal waste discharges. There is no question about that, but it does not mean, of course, that these things cannot be put in the ocean anywhere or under any circumstances. It is possible, of course, to devise a system, a discharge system with at least some method of introduction.

BROOKS: I am glad you brought that up because there are no zeroes in the environmental business. So the question is really how small is small enough for discharge of certain kinds of toxic substances to the ocean. It is true that no matter how good a job you do on source control or pretreatment you simply cannot reduce the toxic substances to zero. With the help of marine biologists, you have to identify which toxic substances have priority for source control and decide what limits are necessary for each substance to protect the marine environment. There has been a lot of debate about what the objectives should be. However, for small amounts of some toxic substances, the deep ocean may be a safer disposal site than anywhere else.

COLWELL: I think in making decisions, one has to consider the long-term effects, even if you change your mind. For example, in the Ottawa River in Canada, there was effluent discharge from a pulp mill which was subsequently banned because of high mercury content of effluent. Nevertheless, a year later, mercury was again detected at high levels in the water column. The pulp mill was suspected of illegal discharge of effluent. However, the mercury was traced to microbial activity in the sediment.

A second aspect is that in some recent studies we have done in the New York Bight where they did a capping experiment, we looked at a species of Actinomyce, which grows only at high temperature. It is definitely a terrestrial organism. You cannot say that it is from the sea. Capping was effective. We no longer pick this organism up in the water column. However, a test of the capping effectiveness was done by taking a core sample, and the organism was found to remain viable in the buried sediment. This disturbance of the sediment, as for example in dredging, will always be a mechanism for resuspension of viable microorganisms from the capped material.

Now a question. With respect to long-term effects, should not you include biological effects in the cost of ocean dumping? Are such cost assessments possible?

BROOKS: I tend to think that it is better not to tangle the societal questions too much with the technical questions, in the following sense. Suppose you have three alternative ways of doing something. It is better to state what the engineering system is and what you believe the effects will be for systems A, B, and C, and also the actual costs of implementing A, B, and C. They will be different, and let the policymakers or the public debate whether the differences in costs in relation to the differences in effects are worth it. I am worried about an engineer or an analyst sweeping it all together in one overall cost, and saying that system X is cheapest when environmental costs are included: The problem is that the environmental cost factors are subjective, and the engineer's choices may be factors of 10 to 100 different from somebody else's choices. Some people say that it does not make any difference: who cares about the ocean? Some say that the ocean is invaluable. So I am saying, "We will just define what the alternatives would do and predict their effects as best as we can, and let the body politic debate which one is worth doing."

I think we have seen, in the last 10 years in the United States, a lack of debate of carefully reasoned alternatives with different costs and effects because Congress just said, "You have got to have secondary treatment, and no ocean sludge dumping." So it seemed useless to define and debate the alternatives.

COLWELL: In Maryland, there is an effort underway to eliminate chlorination of treated sewage effluent because chlorines appear to have an adverse effect on fish larvae. In the winter, chlorination may not be necessary, but in the summer it may be required because of the problem of survival of pathogens. If we have to chlorinate, maybe we should just chlorinate in the summer. There would be a possible survival of pathogen, but when you give this lowered cost you are only giving a part of the picture. You are leaving to the sociologist and economist--

BROOKS: Do not get me wrong. An engineer still should be very much aware of the biological and chemical implications in the design of disposal systems. For example, one of the benefits of making long outfalls is that you may not have to chlorinate in order to meet the bacterial requirements at the shore. In fact, the California Ocean Plan says that, where possible, outfalls should be long enough to avoid chlorination. There is no use in chlorination to meet coliform standards if the outfall discharge is far enough away from shore that natural dieoff and diffusion are sufficient for the coliform standards to be met.

KAMLET: I am curious how far you would take the engineering approach toward this sort of problem. Are there any kinds of waste materials, say, pure PCB's or TCDD or plutonium or what have you that you would be hesitant to try to design an outfall to handle?

BROOKS: Of course, I would be hesitant.

KAMLET: If so, why?

BROOKS: I would always start from the following point. If society has gotten itself into a corner when it has a certain amount of the PCB's to dispose of, then I would do a systematic analysis of all the ways in which PCB's can be disposed of, including the best possible way I could think of to put them in the ocean. Then I would compare that with the best possible way I could do it into other media (air and land) including dispersal and containment techniques, and choose the apparent best alternative overall. The engineering approach for a persistent contaminant must consider possible inter-media transfers, and cross-media comparison of effects. There is no such thing as an engineering solution for one medium when you are talking about such a material.

In fact, one of the truisms I pass on to you is that you really have two strategies for environmental management: either dispersal or containment. These can both be subjected to engineering approaches such as we heard from Professor Dexter on how to engineer a containment.

You get into problems when you do a bad job of dispersal--because with poor dispersal the material is still hanging around too much--or when your containment is leaky. You must not get yourself caught in the middle. You have got to follow either one strategy or the other and do it well. For example, for a landfill for hazardous wastes, you try to make it really leakproof so that the wastes cannot get out in the ground water. But if your strategy is dispersal in the ocean, be sure to do it well!

GAITHER: Thank you, Norman.

ROUND-TABLE PANEL DISCUSSION

Public Law and Regulatory Modification

Moderator: Kevin Healy, General Counsel, New York City Department of Environmental Protection, New York

Panelists: Kenneth Kamlet, Director, Pollution & Toxic Substances, National Wildlife Federation, Washington, D.C.

Richard Sobel, Director, Environmental Control, Allied Corporation, Morristown, New Jersey

Commentary from Panelists

HEALY: We will try to keep this panel discussion informal and allow you people the opportunity to exchange with us your views not only on the topics that we touch on, but also on topics that have come to your mind during the course of the symposium.

Mr. Kamlet is going to go first. He has a few informal comments, that he would like to make.

KAMLET: I would like to just lay out a few ideas, talking points, thinking points, whatever, to stimulate discussion later. I will be relatively brief.

First, I would like to note that neither I nor the National Wildlife Federation is opposed to all forms of ocean waste disposal. This is far from the case. We acknowledge that there are certain waste types, such as biodegradable organic matter, alkaline and acid wastes, and nutrients under certain circumstances that can be readily assimilated by the ocean. We are not opposed to ocean waste disposal under those circumstances. In fact, the Federation has been supportive, under proper circumstances, of incineration of certain chlorinated organic wastes as one of the more appropriate waste disposal options and as a way of taking advantage of the assimilative capacity of both the ocean and the atmosphere in that kind of situation.

We also would agree with the position taken by NACOA (National Advisory Committee on Oceans and Atmosphere) and the position expressed by a number of the speakers in this symposium that waste management decisions should be made on a multimedium basis, that is, after an analysis of multimedium alternatives on the basis of risk minimization. There is no free lunch when you have a toxic waste material; there is no waste management approach that is going to yield zero risk; there are risks associated with whatever you do with such material. So we are fully in agreement that environmental managers--decisionmakers--and scientists, for that matter, ought to try to minimize the environmental risks, with a view toward the overall environment, when dealing with a particular waste material.

On the other hand, I believe that when you are talking about persistent toxic waste materials, the management objective, in general, ought to be to maximize the isolation and containment of those materials in preference to a dispersal oriented approach. If you accept that (philosophy) as correct, then I think it follows that one has to think long and hard before adopting a waste management approach for persistent toxic waste materials that involves ocean disposal.

The ocean is a waste dispersal medium. It is the prototypical example of a dispersal medium in my view. On the other hand, land offers advantages over the ocean, although we all know that land is far from a perfect containment medium. Yet, at least land approaches that perfection to a far greater degree than the ocean does. Although situations such as Love Canal and Valley of the Drums have tended to give land disposal a bad name, I think those are examples of mismanagement of the land as a disposal medium more than they are indictments of the suitability of land for containment purposes when that is carried out properly.

In any case, based on what I think are some fundamental distinctions between land and the ocean, it seems to me all else being equal--and that seldom is true--that when you have a persistent toxic material that you want to isolate and contain, the land has certain advantages over the ocean for those purposes.

Let me elaborate on that last statement a little bit. Containment is one aspect of it; monitoring would be another aspect.

When you have an ocean waste disposal site, whether it is 12 or 90 miles offshore or whatever, it seems to me that it is a good deal more difficult to pull together a crew, hire a vessel, and go out in the vessel to the ocean disposal site and use all of the complicated gear that is involved to take measurements of the ocean bottom--particularly if you are at a deep ocean site where the bottom is very deep--than it is to hop in your car and drive out to a land disposal site and monitor what is going on at that site. It is true that where you have materials seeping into the water table you have to dig monitoring wells and carry out some sophisticated monitoring of that kind. Monitoring can get pretty complicated on land. Yet it seems to me that, by and large, it is more difficult to go out and do the job of physically monitoring the ocean.

Another problem with ocean waste disposal is localizing the disposal activity, making sure that the wastes are, in fact, deposited in the designated dump site. It is a lot easier, obviously, to find the dump site on land than it is in the ocean, although some improvements in radar and navigational techniques make that a little less of a problem. On the other hand, the practice of "short dumping" is still a problem and getting to be more so as ocean disposal sites are located farther and farther offshore. Not all intentional short dumping occurs because somebody wants to put something over on the regulatory authorities or to make a fast buck. Unanticipated storms arise and make it necessary to get back to port as quickly as possible. Short dumping is a fact of life in the ocean disposal context, and while there is illegal waste disposal on land, the short dumping induced by weather changes is not really a consideration at a land site.

Another point, which is not a trivial one, particularly in the context of sewage sludge disposal, is that sewage sludge has some resource value. This is also true of other waste materials. There are ways of beneficially utilizing sludge on land. This has been done in the United States for a long period of time and for an even longer period elsewhere in the world. It is not an unmixed blessing, and it can be abused.

The city of Chicago offers an example. The Chicago Metropolitan Sanitary District has been placing about one-third of its sludge for quite a while in abandoned strip mine areas in Fulton County, Illinois. I think that is a very desirable way to deal with sludge. What I take some issue with, though, is the further step they have taken: to attempt to grow corn and soybeans on the sludge that they applied to the strip mine land and to then market the corn and soybeans to help offset some of the disposal costs involved. I do not endorse using contaminated urban sludge on agricultural food crops in that way. Stopping at revegetation and reclamation of strip mine areas is the better approach taken by the city of Philadelphia, which successfully phased out its ocean dumping last fall. Philadelphia's approach provides a good deal of benefit, in addition to solving a troublesome waste disposal problem.

Another point: I have real problems with the assimilative capacity approach, at least at this point in time, given the crudeness of the available and foreseeable assimilative capacity models. I do not think any of the previous speakers would dispute the fact that our ability to assess assimilative capacity at this point is very crude. Everything depends on your choice of the end points of the ocean's assimilative capacity, and much often depends on data that is spotty, that has huge holes in it. If you couple inadequacies in assimilative capacity models with what I would regard as a pretty rudimentary ability to test those models in the field and measure actual effects in the ocean environment, particularly in the deep ocean environment, I think you have a situation in which you are relying on essentially unverified and unprovable models.

I think assimilative capacity models, even the crude ones we have, can be very useful in helping to define research needs, can be very useful in waving a red flag, as it were, to tell you when, for particular waste constituents, you may be approaching danger levels so that you need to start being especially concerned about what you are doing. I am much less sanguine, however, about using such models to say that it is safe to continue to engage in the waste disposal activity.

It can be hoped that the capabilities of the technique will improve in the future, but I think it would be foolhardy and wrong at this point to place too much stock in imperfect assimilative capacity models, especially given limitations on verification capability.

I also think we need to take the long view on ocean disposal. I think we have to get away from case-by-case cost-benefit balancing, which is what a number of the speakers at this symposium, I think, are suggesting, whether or not they explicitly said so. I really have great difficulty with the logic that in the New York Bight, for example, a single ocean dumper determined to be responsible for producing the entirety of the existing degradation could be required to terminate dumping and forced to implement land-based alternatives, presumably even ones that were somewhat more costly than continued ocean dumping. Yet with 20 or 200 contributors to the degradation problem in the New York Bight we should not require some of them, as long as it was fewer than all of them, to implement a similar kind of approach.

I think a similar sort of logic is in operation here when advocates of using the assimilative capacity of the oceans and the engineering approach toward outfalls and the rest recoil in horror at the notion of disposing of pure PCB's, plutonium, TCDD, or other such materials through an outfall, but have no problem at all with the same total input of such materials into the ocean as long as the materials make up only a small portion of a mixed waste material that gets discharged through the pipe. Admittedly, the problem exists more for PCB's than plutonium or TCDD, which are not major constituents of sludge or other things these days, but I think one can do the calculations for PCB's and get most of the people here to agree that if the quantities being discharged into the ocean in aggregate in New York or in Southern California were discharged in one fell swoop as a solid mass, then such disposal would be an undesirable practice, no matter how much dilution could be achieved through an outfall with suitable diffusers.

Yet most of you would probably have no problem with the same amount being introduced over a longer period of time in smaller concentration, and I think when we are talking about persistent toxic materials we have to look at cumulative loadings. We have to look at the fact that where multiple dumpers or multiple pollutant sources contribute the same aggregate degradation to a particular coastal area, we have to be as concerned about resolving that problem to the extent we can as we are when only one or two very visible and identifiable polluters are responsible for that degree of degradation.

I want to acknowledge that there are some very significant problems in this whole area, obviously. It is not a black and white kind of proposition. It involves a series of trade-offs. From my standpoint the most difficult question in this whole area, even if we could all agree that for a particular waste material the possibility of minimizing risk was greater, far greater on land than in the ocean, the question would be how much is that additional risk minimization worth in terms of additional cost of treatment. That is a very difficult question. It is probably the hardest one that I would have to

confront in this issue. I would have little problem with a cost increment of two- or threefold to accomplish risk minimization benefits. But when you start talking about one-hundred-fold increases, unless the risks involved are pretty palpable and pretty severe, I have little problem in acknowledging that this additional expenditure is too much to have to pay to accomplish risk minimization. You talk about tenfold increase in cost. That gets very much more difficult. Where do you draw the line? How much is risk minimization worth to society, to the sewage treatment authorities, people that pay sewer bills, and the rest? That is a very tough question. I think it needs to be isolated as such, and I think it would be a mistake to try to merge that into the initial question of environmental risk.

I think one needs to determine first what the environmental risk is; what the risk minimization option is in terms of environmental and health protection. Then, in a second step of the analysis, one should decide what, in the way of economic cost, sociopolitical considerations, and the rest, bears on all that. Finally there is a delicate trade-off and balancing process that one gets into, and where one comes out on that is anybody's guess.

In doing the above kind of balancing, it is important to keep in mind that the ocean is a commonly owned or unowned resource. It is operating at something of a disadvantage compared to the land environment. We do not have to worry about purchasing a disposal site or leasing a disposal site or anything of that sort as we would on land. We do not have to worry about neighboring property owners opposing ocean disposal as vehemently as many of the people here have witnessed. A very real problem is the "we-don't-care-where-you-put-it-but-not-in-my-backyard" syndrome. Yet I think we would be making a great mistake to base our waste management decisions on where political opposition is the least.

I think we really need to endeavor to select a management approach and waste disposal medium on the basis of risk minimization. If it can be demonstrated that risk is going to be minimized by a particular selection, I am optimistic, at least, that the public can be persuaded of that fact. Perhaps not the next door neighbors to the dump, but maybe the folks a block away will at least be open to reason if that kind of demonstration could be made. I hope that it would be done on that basis, but I think, in doing the calculations, it is important to factor in not only some of the externalities that various people mentioned earlier--the fishery impacts and the rest that are going to be awfully difficult to quantify--but also the cost of monitoring, an appropriate monitoring plan to actually measure, or attempt to, the fate and effects of pollutants disposed of in the ocean. Relatively little monitoring is done, and what monitoring is done tends not to be underwritten by the dumpers. In comparing the land and ocean options, the cost of an acceptable monitoring approach ought to be factored into the ocean side of the cost for comparison purposes and some other things as well.

Another problem with disposal in the ocean is the need to get some handle on how much impact in the marine environment is excessive. For example a decade-long research program, such as the Southern California Coastal Water Research Project, shows that 5 percent, or whatever the number is, of the ocean bottom and the Southern California Bight has been significantly deteriorated. Somebody has got to decide whether that is acceptable or unacceptable in the way of impact. Should everybody form his own judgment? If I think that 5 percent is excessive, but the waste managers in Southern California think it is perfectly acceptable and, in fact, would find a 50 percent degradation to be perfectly acceptable, then I sometimes wonder what the point of all the research is. To discover that the end result is not going to make very much difference anyway, that a person is going to be convinced that the impact is acceptable regardless of how severe it is, what is the point of putting the money into that kind of research?

I have thrown out some views, laid out some basic concepts that I hope will stimulate debate, and I will just stop at this point.

SOBEL: I am quite willing to act as a stimulus, if I can. My wife asked me last night what is this conference supposed to accomplish. I told her it had already done two things. It had opened my eyes to how little we know about the ocean, but I also told her I had never seen so many Ph.D's in one room. Therefore, there must be quite a bit we do know about the ocean, and this leads to a point.

Seeking to perfect our knowledge about the ocean will probably take forever, just as with the land and with the air. Since we live every day, hour to hour, and since regulated waste disposal, whatever the medium, is preferable to unregulated waste disposal, while we seek perfection, we have to take the best information, the best knowledge we have, and get on .ith the job of developing workable rules. We cannot live with vague, nebulous, detailed, individual risk assessment. A beautiful example, if I ever saw one, was the proposed land disposal regulations which took the risk assessment approach in the February 5, 1891, Federal Register under the Resource Conservation and Recovery Act. There is just no way anybody would ever get a landfill permit or a land disposal permit with all those rules because approval was totally case-by-case, the application required teams of experts, and the entire process just would not be administratively workable in my opinion.

In any event, from my knowledge of industry, I think industry accepts the need for certain of its practices to be regulated. This is off the cuff, but what we ask for in regulations--I do not care whether it is transportation or whether it is waste disposal--is that the rules, first, be based on the best scientific information that is available, not on some unverified hypothesis because of a growing fear in the mind of a certain community. Second, the rules should consider costs, as well as benefits. I am not just talking about economic

costs, but, also environmental costs, and those, as Ken said, are very difficult to quantify. The dollars we can quantify. The other things are tougher. Third, the rules should be administratively workable. The February 5 proposed rules just had no chance in my mind of being workable. The PSD (Prevention of Significant Deterioration) rules under the Air Act approach something that is unworkable. In order to understand the rules, you have to go down to the agency and talk to them. Maybe someone down there understands them. Fourth, the regulations should be flexible enough to allow for variances and equivalent compliance systems. Do not give us a fixed rule that says, "This is the way. I have 10 judges and four Ph.D's who say so, and there is no acceptable alternative." That is never true, but we like to see mention of alternative approaches in the regulations so there is no question in the minds of the permit workers.

Businesses also need information for planning purposes--because businesses work on a plan just like a research program works on a plan--they like to know one year, five years, ten years ahead where they are headed. Businesses need to know what their people requirements are, what their financial requirements are, and many other things. We cannot live with a regulation that changes twice a year.

Businesses need a permit that lasts long enough to justify an investment. They do recognize that the state-of-the-art changes and that regulations may change also. But a five- or ten-year period is a desirable minimum for most permits, and for facilities, like landfills, a lifetime permit is desirable. This would encourage investment even though the permit will have to be reviewed from time to time.

Those are some general comments.

The topic as stated in the agenda is something about laws and regulations. So I will throw out a few additional thoughts on the law and the regulations.

As has been said half a dozen times, the various environmental statutes need to be examined to see what is needed in each to make sure other media can be used. Under the Clean Water Act there is a requirement that if there is an effluent guideline promulgated in the regulations which says so many pounds per million tons of product is allowed in the effluent, then an industry has to meet that guideline regardless if it is discharging to fresh water or to the ocean. I think this happened in the case of titanium dioxide. Such provisions in the laws may be impediments that will not allow the ocean to take its proper place alongside other media because impacts on the receiving waters are not considered.

As to regulations: the regs that govern judging the need for ocean disposal should be clarified, or a guideline needs to be written, or some instrument needs to be developed that levels out or minimizes

the differences among the 10 EPA regions in administering these regulations. Most regions have taken the policy approach that says, "If you have a way out, you are going to get out." Very few EPA regional staff were willing to listen to you, read the rules, and say, "Okay, let us march through them a step at a time and see what they say."

Technical standards may need review also, particularly the limiting permissible concentration and the bioassay requirements. Whether the standards are up-to-date, whether they reflect the best information we have today as opposed to roughly 10 years ago when they were put together, I do not know. It just might be worth a look.

Dump sites. As I said, there are only three industrial sites: one in Puerto Rico, Dump Site 106, and the acid site; all in Region 2. Sites need to be designated ahead of time, possibly for certain kinds of wastes, and that, of course, has to be based on inventories and studies on the water. What are the best places to put these wastes? We should not limit ourselves just to previously used sites, such as these three.

Fourth, I mentioned that a trial dumping permit might be useful to EPA to get over the problem I heard mentioned several times, that the laboratory evidence is tough to extrapolate to the real ocean environment. Maybe a trial dump would be useful in getting some actual effects, rather than just theoretical or extrapolated effects.

There are probably other adjustments to the regulations that would be useful and practical, but I would like to focus on a related problem. The EPA has been so successful in eliminating industrial dumpers, that there are only three companies that will continue to dump at the end of this year (1981). Therefore a lot of the business community's expertise is probably dispersed. Yet to take part in the regulatory development process requires people who understand the problem. Furthermore, instead of dealing with existing practices, we are going to be dealing with hypothetical practices. So industry may have some problems in developing a proper input to these regulations if they are changed. We can always get experts like you people, but it tougher to deal with a possible future situation than it is with an actual existing situation.

Thank you.

HEALEY: Taking my passing swipe at the topic of what to do with regulations and statutes, my main problem with the way Environmental Protection Agency has implemented the Marine Protection Act is that it seems to have skewed the curve somewhat artificially in favor of discouraging disposal in the ocean.

The agency has established the subpart B criteria, applied them, and if you flunk it, you are out, as a practical alternative. The EPA

has not taken the second step of trying to figure out what is going to happen on the land if you have to implement some sort of alternative to dumping.

My feeling is that if you apply a bioassay test and a fish is killed, the stuff that you tested might also kill a bird or something on land. Given that possibility and given the experience that we have had in New York City, I feel that we have really got to take a look at exactly what is going to happen if we cannot use the ocean.

Let me give you the New York City example. We were faced with the December 31, 1981, deadline. In response to that deadline, we were trying to develop a composting program in the city of New York. We intended to establish gigantic filter press operations in various places around the city and take the approximately four million wet tons of sewage sludge that we produce a year, dewater it, and take it to a composting facility on Ward's Island in the East River. After composting it, we would distribute the resulting material around the city.

As we began to implement that strategy, we thought that we had not given enough consideration to the exact consequences of spreading the material, which contained persistent organics and toxics, around the city of New York, one of the most densely populated areas in the world.

I do not believe that if we had gone ahead and fully implemented that program there would have been a environmental disaster. I do think the city of New York would have spent millions of dollars, and the federal government would have spent millions of dollars in trading off what is essentially one pollution problem in the media, the pollution of the ocean, with another pollution problem that might be equally bad.

As Ken Kamlet said, there are problems with dumping in the ocean, and there are benefits in putting the stuff on land. One of the main problems with the ocean is dispersal. One of the main benefits of the land is containment.

The problem with the land is, once you put wastes someplace, it is there along with any persistent organics or toxics that remain for a long time. We are talking about a problem that is going to be there forever. One of the problems we had with composting in the city was that the material that we were going to be spreading around did not meet the Department of Agriculture criteria for growing crops. People thought that was relatively amusing: growing crops in the city of New York. But you have to understand that we are talking forever. We would be precluding urban farming in the city of New York for a millenium. So there are problems with skewing things in favor of one medium, and in New York that was brought home to us pretty clearly.

Incidentally, to get out from under the problem, while we were complying with the deadline--and we could have complied with the deadline--we also asked EPA to review its interpretation of the statute and to really take a look at the land as well as the ocean. EPA did not read the statute the way we did. They did not think they had that kind of room to move. So we had to sue them. A court, as you probably know, recently found that our interpretation of the Act was correct. The deadline only applies to wastes which unreasonably degrade the ocean. That decision puts sludge into the same boat, so to speak, as other waste. EPA, under Section 1412 of the Act, must determine whether sludge and other materials have characteristics that might unreasonably degrade the ocean, or are harmful, but finding that, EPA then must also examine the need for dumping. They have to make a real projection as to what is going to happen if you implement the technologically feasible and available alternative to dumping, and they also have to find out, according to the judge, what the actual impact of dumping will be. I consider that decision as an opportunity for EPA to do what people, including Mr. Kamlet, seem to be saying that the EPA should be doing: which is, to examine all the options and figure out what the best place is for a particular material, to determine what is going to happen to the air if you burn it, to find out what is going to happen to the land if you compost the waste and spread it around.

So, I think that EPA now has an opportunity to begin to balance its approach and do it right.

Comments from the Floor to the Panelists

GOLDBERG: I just want to make one point. There is a problem of disposing of terribly toxic materials. Let me suggest that we are doing this now extremely effectively. This is done using the Windscale outfall of highly toxic radioactive waste in the Irish Sea, which is done under the critical pathways approach.

I do not want to go into all of the details, but let me point out that perhaps the most important environmental document in the last decade, in my opinion, was the Parker report, which assessed the extension of the Windscale outfall reprocessing plant to handle more waste. This was done by Justice Parker, who is a lawyer, and he had with him a scientist and an engineer who assisted him in the evaluation as to whether Windscale should be expanded.

I was a consultant of Friends of the Earth, who took the position not to fight on environmental grounds, only on economic grounds. The environmentalists did not fight this on environmental grounds whatsoever, only on economic grounds. This continues to occur, and I think

it would be very difficult, at least for me, to attack very successfully this dispersion into the ocean of highly toxic materials with the banner of protecting human health. I would be much more concerned about trying to find a containment mechanism to keep it on earth because there is no black box that does not leak. You put it in the ocean, and you disperse it, and period. Read the Parker report.

KAMLET: Let me make a comment, not specifically on that, but I think it is related. I do not think I indicated that I was totally opposed to disposal, even of persistent toxic materials in the marine environment. But it seems to me that there is a rather heavy burden that needs to be overcome before that sort of activity could be regarded as acceptable. I do not know whether that burden has been sufficiently overcome in the Windscale situation. I am not familiar enough with what has gone on there, except that I understand there is a certain amount of scientific controversy about the success and environmental safety of the operation, but I may be wrong there.

The point I would like to make is that the ocean is different. The ocean is by no means sacrosanct. It should not be regarded, based on environmental impact considerations, as separate and apart and deserving of special protection compared to other media. Nevertheless, the ocean environment is fundamentally different from other media in the sense that it is not subject to private property kinds of mechanisms.

A number of years ago, the United States Congress took some action with respect to public parks, which I think are analogous to the ocean in this sense. Congress specified in the Department of Transportation Act and the Federal Highway Aid Act that before you could use federal money to build a highway through a public park you had to demonstrate (a) that there were no feasible and prudent alternatives and (b) even if you had made that demonstration, that all possible planning had been done to minimize harm in building a highway through the park. A need was felt for the federal government to intervene in that situation because, given the public property nature of a park, that, without that sort of special protection, highway builders would always prefer to build a highway through a park where that opportunity existed rather than going through a populated area where people would be displaced. In the latter case an inevitable public opposition would arise.

I think the analogy to the ocean is a very good one. I think there is a special need for governmental protection of the ocean because the sea lacks other protections that apply through the economic system to privately owned property on land. I am not saying that the ocean ought to be off limits to waste disposal. All I am saying is that it should be at least marginally more difficult to use the ocean for waste disposal than another medium. If it were found that waste disposal in the ocean and disposal on land had exactly

identical environmental impact potential, then, in that situation, the land should be used for disposal rather than the ocean. On the other hand, if there was even a slight advantage to use of the ocean from an environmental standpoint, I would not have a problem, if the analysis were done properly, with use of the ocean under those circumstances. But I think there are some differences that make the ocean especially vulnerable to misuse that have to be kept in mind in a regulatory context and for purposes of evaluating the things this symposium is all about.

CSANADY: I would like to go back to another comment of Ken Kamlet's on the accuracy of modeling. It is true enough, of course, that we do not have particularly accurate models, and what we rely on can be quite legitimately described as crude, particularly when it comes to ocean disposal far from shore. However, those models may be crude, but they are quite good enough to tell us some gross things. For example, acid waste has an oceanic lifetime of the order of a day or two if you dump it 100 miles from shore in deep water. Nowhere will there be any effects of that on the shore. The only other question that remains is possible effects on the marine life in the area. Then it becomes very much a question of how much of the ocean, what percent of the ocean, will be significantly influenced. At that point, one can very easily come to a legitimate conclusion that ocean disposal is far and away the best method because, without going further than such a crude model, you can be absolutely sure that we would not see any effects of that acid waste on major spawning areas of anything like this. One can have a very high degree of confidence in spite of the crudeness of the models.

The crudeness of the models is limited to some kind of neighborhood of an operation. Beyond a certain neighborhood you can be quite sure that we are not going to cause any effect. So, in that sense, given the huge space available in the ocean, those models are not necessarily always crude. They are crude in some sense, but in certain applications they could be quite acceptable.

KAMLET: I recognize that what you are saying is true, and you are undoubtedly correct that, as far as physical forces are concerned, there is a very slight probability that waste dumped at the deepwater Dump Site 106 will wash up on a New York or New Jersey beach.

On the other hand, there are biological processes in operation as well that are superimposed on the physical ones. When I consider, in the case of an acid/iron waste, to use your example, that a ferric hydroxide floc forms that can persist for two, three, or even more days in discrete form in the ocean, and when I further consider the fact that other somewhat more toxic industrial wastes are probably being dumped at the same disposal site although not necessarily in very close time or space proximity to that operation, and then if I add to that the fact that organisms, mobile aquatic organisms, often

have a tendency to be attracted to waste plumes where they have that opportunity, and in the deep sea one might expect organisms that find it hard to scrounge for food to be especially able to detect potential food in their vicinity, I have the concern that the potential for biological uptake by mobile organisms at Dump Site 106 is not a trivial one. Whether or not there is a related significant potential for human consumption of contaminated seafood resources I do not know. Perhaps that potential in the near term is small, but what troubles me is the continual addition to the background levels in the environment, in fish tissue and in the rest of persistent toxic contaminants. Sometimes I think that we are making judgments in these areas that could be very significant, if not within the next year or two then in the next century or two, on the basis of really inadequate information, particularly with respect to biology. It is true that it is not a problem unique to the ocean, but sooner or later we are going to have to come to grips with the uncertainty factors and how much we, as a society, are going to be prepared to pay in the interest of avoiding uncertain harms that may be fairly significant.

HEALEY: Now your comment about the crudity of modeling made me think of something that may be incorrect. I might be terribly wrong --but let me make an observation anyway. In the past 10 years, air quality modeling has become very sophisticated, and the reason, I think, is the understanding that air pollution is going to be a persistent problem. Now in that 10-year period, EPA has been concentrating its efforts on phasing out ocean dumping. If it were to be understood that ocean disposal and ocean pollution are going to be facts of life, my guess is that models in the ocean would become much more sophisticated than they are now. There would be a lot more emphasis on managing the pollution of the ocean in a way that would minimize the harm to the ocean.

CSANADY: Just to come back to Ken Kamlet on that, I still think that I was not speaking only in physical terms. When one takes into account all those possible interactions that you mentioned, it is still possible to make a model which might be crude but is quite good enough to show us that the risks involved in this kind of operation are quite minimal.

You brought up the persistent toxic compounds. I did not specifically mention those. Perhaps they require, in the long run, a much more sophisticated model, but here, as in all these questions, we ought to consider quantitative matters right from the start. Where we stop each other is when we do not become quantitative. How persistent? What do you mean by persistent? A 10-year lifetime, is that persistent? Actually 10 years is almost non-persistent as far as the world ocean is concerned because, by the time you mix it through the available volume, it has decayed. Therefore, as far as the dispersion strategy is concerned, such a lifetime is quite acceptable. It is quite feasible to use dispersal strategies in cases like that. Very

few substances live to the two- or three-century time scale that you are talking about. Very few substances will stay in the ocean for hundreds of years without either decaying by some natural process into a harmless or neutral end product or being incorporated in the sediments and therefore buried as well as you could ever bury it on land.

ENGLER: After hearing your opening comments I am getting very depressed. I did not hear many answers, a lot more questions and problems, but in keeping with the panel's topic of public law and regulatory modification, I have got a series of problems with the way we work now in the regulatory business and I wonder if you have some ideas in solving these.

I will touch on three of them. One is the overlapping and contradictory laws: Clean Water Act, Ocean Dumping Act, and now RCRA (Resource Conservation and Recovery Act) superimposed on that, and the regulations that implement these laws are, again, overlapping and contradictory.

Dick Sobel touched on the inconsistency of interpretation. It is unbelievable for the Corps district-to-district and EPA region-to-region. How do we overcome that? How do we overcome the inconsistency of interpretation among the other resource agencies that are in the permit review process, the so-called "stumbling blocks?" I note that Fish and Wildlife is not at this symposium. Finally, another problem is the ill-defined end points that we have in our laws and regulations.

Any comments?

KAMLET: I have some comments. I am not sure you will like them. I think one way of minimizing the inconsistency is to lay out more specific criteria rather than less specific ones. I think one of the main themes of the people that have spoken at this symposium thus far has been a plea for more flexibility on the part of decision makers, less effort on the part of regulators to limit the options that decision makers have. I think you pay a price in that kind of approach in having inconsistent approaches taken by different decision makers around the country.

I would prefer to see a fairly rigid regulatory approach to guide initial decisions, but supplement that with some sort of safety valve mechanism, a waiver process, variance, or whatever where the more subjective judgment enters into the process rather than to start off with very vague general guidelines that no two people, let alone no 10 different people, would construe in the same way. I think a start toward resolving the problem of inconsistency, which was one of the several that you mentioned in your comments, would be to lay out more in the way of pretty specific pass/fail criteria in the basic regulation and then take account of unique differences and circumstances

through some safety valve mechanism or variance procedure or waiver mechanism, something of that kind. I think that would help to resolve some of the inconsistency and yet provide enough flexibility to decision makers to take account of real differences in different cases.

HEALEY: I think that your problem is somewhat solved because of the way the Marine Protection Act is now drafted and interpreted, specifically the application of the unreasonable degradation standard. What should happen, I think, is that, in determining whether there is an unreasonable degradation, EPA should have to determine what is going to happen if you do not dump the stuff? Specifically they would have to take a look at what is going to happen insofar as air potention is concerned if you are going to burn it. Will you violate an air quality standard? Will you get into problems with the national emission standards perhaps as air pollutants? Will you get into some problem with the Clean Air Act? Will you get into some problem under RCRA applying the specific criteria that are established under those statutes? If you apply the unreasonable degradation standard and, in so doing, comply with the standards that are applicable under the other environmental statutes, you are not going to have the inconsistencies that now are apparent.

ENGLER: A related problem I have is the number of other agencies that in the review process have, in essence, a veto on the permit. It may not be a veto per se, but it stalls the permit long enough so that the applicant either gives up or has to expand siginificant funds to push this along.

How can we continue to factor in the environmental resource or the resource review groups such as Fish and Wildlife, National Fisheries? How can we continue to factor them into the regulatory process as complex as it is now? There are too many bosses to the fellow coming through with the permit in hand.

SWANSON: Ken Kamlet, I would like to have you comment on the fact of whether the regulatory process is working at all and whether it is worth going to the expense to have a regulatory process. I go back to our case of one year ago where the PCB's in dredge material in New York Harbor apparently did not pass the bioassay test. The name of the game was not what we do with material that has failed the test, how we dispose of it in some sensible way: the name of the game was how do we change the rules and regulations so that we can legally dump it.

Can you comment on that?

KAMLET: I agree with you about how the PCB problem you described was handled. I think you are absolutely right that the orientation at the time was not to try to resolve an underlying problem but to try to define the problem away. I have spent a lot of time trying to get

around difficulties of that kind. It is extremely frustrating. I have to admire the ingenuity of the Corps of Engineers in coming up with new ways to interpret the ocean dumping criteria for dredged material to allow dredged material to continue to be ocean-dumped, arguably consistent with those criteria, but you are absolutely right that that is "no way to run an airline." I think what is needed is a set of criteria that perhaps lack total consensus but at least reflect some general agreement on what within the relevant regulatory community is a valid, sensible way to go, whether on an interim or a long-term basis. Then we need to stick to those criteria, not try to change the rules of the game after the fact.

So I think we do need some predictability in the process, and that means having criteria that mean what they say and are interpreted in that way.

ENGLER: Ken, I am a little distressed that you accused the Corps of changing the rules. The rule is very simple. It says that you dump as long as there is no significant undesirable effect from dumping. We had a PCB problem, and it looked as though continued dumping would not change the PCB concentrations in the creatures at the dump site at all. At that point the environmental resource manager made the determination that there was no significant undesirable effect from dumping. Live with the status quo. That is not changing the rules at all. That is simply how we interpret "significant undesirable effect," and that interpretation was fine for the New York Bight. It would work equally well for the Gulf Coast. Calcasieu River (Louisiana) material contains extremely low quantities of PCB as a consequence, and the dump site contains no measurable amounts as a consequence.

GAITHER: I think we have reached the point here where we had probably better stop. Panel, I would like to thank you very much for serving as a forum.

We have one more item in this symposium, and that is the summing up, and this will be done by Dr. Davis Ford.

SUMMING UP:

THE NEED AND TECHNICAL RESPONSE IN USING THE OCEAN FOR WASTE DISPOSAL

by

Davis Ford*

I think this is rather a dubious honor, to take only 20 minutes and summarize all these very interesting comments.

I think that I would like to take about 10 or 15 minutes and use primarily the third person with license to use a little first person singular from time to time and summarize what each of the speakers said. I will do this chronologically. Then, I will use my own words to try to summarize this particular symposium.

The first speaker, Dr. Goldberg, talked about the Crystal Mountain report. He talked about the basic result of that Crystal Mountain report, namely, the assimilative capacity is not fully used. He indicated the major problem is probably eutrophication of marine waters.

Then we got into modeling aspects, the difficulty of modeling, the crudity of some of our modeling. I thought that was quite interesting, and particular emphasis was given to modeling suspended material as compared to soluble material.

Dr. Csanady noted that temperature distribution problems were very complex with the thermal barrier problems that we have. He said that ocean waters did not mix well and the quantification of mixing is not well known. It was also interesting that he indicated, quite correctly, that so many random events take place that this really leads to probabilistic modeling. He made one comment of which I made a particular note of, namely, the tail of the probability curve is always the problem. I think that is a very good point for us to keep in mind.

Then we got into the mysticism of biological prediction. Really, as an engineer, I enjoyed some of those comments because I have always felt that that was the case. There is a lot of mysticism in engineering, but if there is mysticism in engineering, there is really mysticism in biological predicting.

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Dr. Phelps made some very good points, I thought, namely, cause and effects which are very subtle. If I can just take, for a minute, a closed biological system which we can control, for example, an activated sludge system. I have always been amazed by the response of the biological population to just very slight changes in the waste mix. Here we have total control. We can quantify a lot of things. We see these responses change. They are very subtle. It is a very slow shift in populations as we change the product mix through the waste water coming into that closed system. This leads me to question the use of a word that has come up time and time again: end point. I think it is a very poor word to use in describing the assimilative capacity of the ocean. I think Dr. Brooks indicated that when he said that there is really no threshold of assimilative capacity. Maybe it is a battle of semantics, but I get the feeling that we are assuming a titration phenomenon when suddenly there is a dramatic, change in color. This is certainly not the case in talking about assimilative capacity.

We also indicated that the assimilative capacity of the ocean can be exceeded, but it is not widespread and is site specific. That is one term that I want to use again and again, the specificity of the assimilative capacity of the ocean.

Also, the point was made that we know more about the ocean, even with our crudity in modeling, etc., than we do about the subterranean waters inland. I really think that is a valid comment. I have had the opportunity to look into a lot of situations where the aquifers are polluted, and I do not think any of us in this room really understand how many aquifers in this country are contaminated. It is much more than we surmise.

I do not know very many people who drink ocean water, and I know a lot of people that drink water from aquifers. I think we have to put that in perspective when considering the alternatives of land disposal versus ocean disposal.

As we got into radioactivity, radio isotopes, and ocean dumping, there is one comment that I picked up. That is the remark that assimilative capacity and site specificity is a kind of shell game where you have three walnut shells with a pea under one. I remember a political cartoon that came out in the Austin paper about three or four months ago, showing Secretary of State Haig with the three shells and asking Brezhnev, who is looking at him very condescendingly, "Under which shell is the MX missile?: whereupon Brezhnev slams his hand and cracks up all three of them.

I think that is the kind of a shell game that we play in this assimilative capacity of site specificity of ocean disposal.

Then we got into the discussions about how much the ocean can assimilate in terms of radio isotopes--how we should package the waste. I am very interested, Steve Dexter, in your comments with respect to evaluation both on a short-term basis, which I believe was 13 or 14 years, as compared to studying what the Romans did. That should give us some kind of spectrum if we can just quantify it in between.

When we got into the topic of monitoring, some very interesting comments came from the floor. There have been a lot of capricious approaches to monitoring that produce reams and reams of data, requiring large amounts of money, and the data are not used for input into anything. The data are possibly used to draw esoteric conclusions, but do not really lead us into a step-by-step solution to any particular problem.

Nonetheless, as we get into the regulatory approach on doing the unknown, we are subject to heavy monitoring requirements, and maybe that is a good alternative. Again, this is a very difficult and a very multifaceted subject to discuss.

It was mentioned that monitoring is a major function as a marine disposal management tool. That is certainly true, and a point was made that we must tie effects to sources which is necessary for enforcement.

Cumulative loading effects, bioaccumulation--again, a very difficult thing to quantify, were discussed quite appropriately, and I am not sure we really heard any particular solution on that--which leads into our discussion on dredging.

Dredging was put in perspective: 300 million cubic yards of maintenance dredging per year, another 300 million cubic yards of new dredging. It is just an overwhelming problem. I did not realize myself, until Dr. Engler's presentation raised the point, just how significant that is. I was interested in your list of 11 obvious impacts.

Several presentors made the comment that EPA states, in effect, that ocean dumping is the most restricted of the candidate systems. Yet they believe the ocean should be on equal footing with other media. I would certainly concur with that. Most of the comments that I heard yesterday and today also seem to concur on that particular point.

I will not make any particular comment on the discussion on the Los Angeles County Sanitation District experience. I thought that presentation was quite interesting, probably one of the best case histories from which to draw information relative to disposal of sludges and liquid waste.

I was particularly interested, however--and this leads to one of my basic interests--in discussion of the cost effectiveness of the alternative systems. As I recall the comments on the Los Angeles County case history, we are talking about factors of two and four on costs, for example, when comparing partial secondary treatment to total secondary treatment--a factor of two on the amortized capital and operating and maintenance costs. Quite significant. When we talk about the possibility of sludge discharge to the ocean, we are talking about a factor of four according to Dr. Brooks.

It seems to me when you get into these cost differentials, then you place less emphasis on the species diversity index for some of the more esoteric biological parameters.

This leads to a list that I jotted down as we went through the symposium. I did not hear anybody recommend anything against ocean disposal. I think everybody is pretty well attuned to that. We get into more difficult areas of quantification when we approach policy.

Bob Wiegel made a comment, which I think is very appropriate. He said that we should look at really stressed bodies of water in determining what cause and effects have been. I do not believe--maybe there are a few exceptions, possibly the New York Bight--that we have any real stressed bodies of ocean water, on a relative basis, on this country's coast. I say that, for example, by looking at the Atlantic right off the coast of Casablanca where the only treatment is a pipeline, which is dumping raw sewage; there are many different outfalls within a distance of about two miles. The Dardanelles and the Bosphorus are really stressed. Lake Maracaibo in Venezuela is a brackish body of water, a positive estuary, that receives municipal waste water which has virtually no treatment. Batea, in Maracaibo, is a lift station designed by my company. So, I think we have good baselines of information from which to draw real causes and effects to utilize for our own data base. I do not think we should be blind to this availability of information and not use it appropriately.

Probably one of the better examples of a stressed water body is the Mediterranean. There have been many studies on the Mediterranean. There are tremendous stresses in local areas, for example, Southern France, Italy, Yugoslavia, and minor stresses in the other areas of North Africa. There is extensive background information that is available to us, that we need to incorporate into our data base, and we should take advantage of this particular repository of information.

Another comment that I would like to make is the necessity for interrelationships between the three media: air, land, and water. That has been mentioned so many times. I do not want to get into platitudes, but I would just like to underscore the necessity of considering intermedia relationships. The disposal situation is like a balloon filled with water: you compress one side and the other side

expands. So it is the overall macro system that we look at, and I think we all have the responsibility--and I believe most people agree with that--of looking at the situation on an interrelationship basis. If we do not go to ocean disposal, for example, what is the corresponding environmental impact on land?

The next comment I would like to make is the "degree of hazard." Again, this may be platitudinal because many of you have heard that before. I guess one of the problems that I have with the Resource Conservation and Recovery Act (RCRA) is it is black and white. A substance is listed or it is not listed. It passes the criteria or it does not pass the criteria. We got into that discussion to some extent on the concentrations. We have been focusing on PCB's and DDT, presence or absence, with no discussion on the effects of concentration.

Another subject that was noted, Dr. Brooks did not talk about it in his discussion today but it was in his paper, and that is source control. We have not really gotten into that subject too much. As many of you know, kinetics of removal favor highly concentrated contaminants and low flows in terms of cost-effectiveness of treatment. We have given lip service to that in the past, but we do have many, many opportunities to environmentally enhance an industrial sector through source control of materials that do persist in the environment.

Source control can be relatively cheap when considering the options. We have the technology in most cases to do that without really altering the manufacturing process. So, I think source control, plus a more effective water reuse within the industrial sector, will certainly reduce the load to the environment.

The Germans have done this effectively. For example, water from the Ruhr River is used 100 times before it reaches the Rhine and the water quality at the confluence is not that bad. So we know the technology is there. It is just a matter of implementation.

The comments on biochemical oxygen demand (BOD) with respect to secondary treatment prior to ocean outfalls are valid. BOD is not a significant parameter in that context, and maybe another context. I think, again, we have to focus on the more persistent compounds in nature and not necessarily the dissolved oxygen aspect of it.

The "_a priori_ ban" of sewage sludge disposal, I believe, is totally myopic, and I think most of the speakers have stated that throughout the day.

I noted earlier the aquifer contamination problem when disposal on land is used. I might add one comment to Ken Kamlet's comment about the ease of monitoring. When you get an unconfined aquifer as

on Long Island, one big unconfined aquifer with some degree of contamination, it is just a terribly difficult problem. I have a particular case in mind. On Long Island we are talking about drinking water which is derived principally from groundwater, containing contaminants with potentially adverse effects on human health. We have to understand that for many of our aquifers, it is very difficult to quantify what the movement is going to be, and how to treat it once you find it. How do you treat an unconfined aquifer with a fairly high concentration of, say, benzene, toluene, xylene? The only thing I know to do is pump it up, treat it, and either reinject it or dispose it to a surface water. This is expensive and tremendously complex from an engineering point of view.

I guess I will revert back to first person singular on the matter of regulations. And in effect, I am really endorsing what others have said.

I have seen unfold in my professional lifetime RCRA, the Clean Air Act, the Safe Drinking Water Act, and other statutes. It is difficult to interpret the many regulations. I have never understood how a little statute can spawn regulations so big, and I think this transition is one of the main problems we have.

I remember after I got the RCRA regs--when was it, May 19, 1980, when the RCRA regs first came out--they were confusing and led to total frustration. I am sure many of you share that view.

This leads us maybe to one final conclusion here, and it is just one of many things that we have to consider. We simply have to develop some way of quantifying these very complex, multidisciplinary facts into a useful tool that allows us to evaluate ocean disposal versus some other alternative such as land disposal or incineration.

We can talk about it. We can be esoteric, but at some final point we have to establish quantities for these. We could talk about all these medium variables and process variables that have been discussed these last two days--such as diversity index, concentration of PCB's, and then some of the modeling input that we would have such as degree of dispersion, definition of mixing zones, and so forth.

Now this is a very difficult thing to do. But it just seems like we have to simplify a lot of these things down to a working tool.

I believe, that pretty well summarizes the comments that I have.

GAITHER: Thank you very much, Davis. We hope that for the Marine Board members here this has been an educational process and worth the time. I particularly want to thank the speakers, the members of the Steering Committee, and the participatory audience.

APPENDIX A

ALTERNATIVE STRATEGIES FOR OCEAN DISPOSAL OF MUNICIPAL WASTE WATER AND SLUDGE

by

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OVERVIEW

Our knowledge of transport, fates and effects of water pollutants has increased considerably in the last decade and further advances of knowledge are expected. Management of ocean discharges should be directly related to our present understanding of ocean processes, but flexible enough to be adjusted in the light of new research results; in addition, alternate disposal processes to air or land should be evaluated. The ocean disposal option should have technical parity with land and air disposal options.

The technical problems of discharge to the ocean are different from discharges into rivers or inland waters or estuaries. The ocean has great value for assimilation of wastes and the policy governing it should be separate from discharges into other bodies of water. For example, biochemical oxygen demand (BOD) is rarely a problem for ocean discharge, but for discharges to certain inland waters it may be an overwhelming problem that necessitates secondary treatment.

This paper* briefly discusses management alternatives in the context of our current understanding of the needs for controlling ocean pollution from municipal sources.

A. Predictability of Outfall Effects

Effective management of wastewater and sludge discharges to the ocean depends critically on the ability to measure and predict the effects of treatment and outfall systems. The design of new or revised outfall systems is based on certain water quality objectives to be satisfied by the system under design. Fifty years ago outfalls were designed simply as hydraulic pipelines into the sea with the location and length decided either by guessing or by pure judgment, without any scientific analysis of the resulting water quality in the ocean.

In the intervening years, the state-of-the-art has advanced considerably, especially in the physical aspects of design (Fischer et al., 1979). In the design of outfalls we can now do the following predictive analyses quite well:

(1) initial dilution for a multiport diffuser, taking account of environmental factors such as ambient density stratification and currents;

(2) maximum height of rise of the initial plume in a stratified ocean, i.e., the level at which neutral buoyancy is achieved between the diluted plume and the ambient ocean and further spreading is done as an internal flow;

(3) frequency of advection toward shore and probable travel times;

(4) coliform die-off and expected coliform counts along the shore;

(5) maximum dissolved oxygen depletion based on dilution;

(6) order of magnitude of regional flushing based on oceanographic variables;

*This paper is essentially an abridged version of Chapter 13, "Evaluation of Key Issues and Alternatives" by N.H. Brooks, forthcoming in the book The Impact on Estuaries and Coastal Waters of the Ocean Disposal of Municipal Wastewater and its Constituents, Edward P. Myers, editor, sponsored by National Oceanic and Atmospheric Administration, to be published by the MIT Sea Grant Program. The views expressed herein are solely those of the authors, and do not represent the policies or positions of NOAA.

(7) rate of dissolution of particulate forms of metals on sewage particles; and

(8) substances likely to be bioaccumulated in the food chain and to require special attention and source control.

We have good empirical observations, but less ability to predict, with regard to things like the following:

(1) settling velocity of particles as a result of flocculation in the ocean;

(2) size and extent of resulting enriched patches on the bottom near outfalls;

(3) detailed ecological effects of wastewater, other than by empirical comparison to existing discharges;

(4) biochemical conversion of trace contaminants to more toxic forms by marine organisms; and

(5) rate of degradation of potentially toxic persistent organics.

None of the predictions are exact; there is a degree of uncertainty. (The reliability of the various predictive modeling techniques is described in detail in the forthcoming NOAA book cited in the footnote above.) However, the performance of an outfall is not fixed but follows frequency distributions driven by variations in the ocean environment (the time of the year, storms, tides, etc.). Consequently, when all the factors are considered and conservative assumptions are made, recent design experience has been successful in meeting the prescribed sets of water quality requirements.

In summary, the development of outfall structures to achieve very high dilutions (over 100:1) in locations of good coastal water circulation has been instrumental in achieving good disposal for the conventional pollutants and pathogens. In many locations, secondary treatment is not necessary as part of the system and primary treatment is sufficient.

In recent decades, however, we have failed to predict the effect of trace contaminants such as DDT and PCB's because of their persistence in the environment and bioaccumulation in the food chain. It is now generally agreed that management of this part of the ocean-disposal problem depends not on better outfall designs or more advanced treatment, but rather on controlling the release of hazardous substances into the sewer system in the first place. By measurements of the effluent for trace contaminants it is easy to establish which substances need special attention and source control, and it is easy also to measure an agency's progress toward that goal. What is not within

the state-of-the-art, however, is deciding what values of various trace organics can safely be discharged to the ocean. As instrumentation gets better, we expect to find that, for many substances undetected until now, the concentrations are small yet measurable quantities. Since we do not know how small is small enough, we have to take some risks, but these risks are no different and perhaps less than similar risks we face constantly in all parts of our environments, vis-a-vis trace contaminants.

B. Toxic Substances

One clear point of understanding is that the ocean can safely be used to receive reasonable amounts of waste water, provided we improve our ability to control the entry of toxic substances into municipal sewer systems. The overriding future risk of ocean discharge of municipal waste is the intentional (or unintentional) introduction of long-lived toxic substances into the marine environment in concentrations which may be damaging to marine ecosystems, or a threat to human health through consumption of seafood. Since similar threats of toxic material exist also in air and on land, the ocean problem is not likely to be solved by a displacement of such substances to another environmental medium. Rather, there is a consensus that the best approach to control of toxic substances is at their sources. There must be a change in the general attitude that sewers are for dumping anything that you want to get rid of.

The concept of source control or pretreatment for municipal sewer systems is to reduce or control the amount of a trace contaminant entering a sewer system from industrial plants or other sources. This is probably the most cost-effective approach--or possibly the only viable approach. To allow hazardous substances to enter the sewer system in excessive quantities creates what appear to be intractable problems of disposal. If the hazardous wastes are captured in sludge by the sewage treatment process, then there is a problem of safe disposal of the sludge. On the other hand, if they pass through to the ocean there may be risks to the ecosystem or human health. In the discussion that follows, we assume that good source control or pretreatment is being implemented.

C. Treatment Processes for Ocean Discharge

When conventional secondary treatment (activated sludge) was invented, its main objective was to reduce the biochemical oxygen demand (BOD) of sewage before discharge into freshwater bodies with limited oxygen resources. However, BOD is not generally a problem in the ocean, and the priority of treatment of traditional pollutants is particle removal (i.e., suspended solids removal). Indications are that conventional primary sedimentation may remove about 50 to 60 percent of suspended solids, whereas secondary treatment can be

expected to remove 85 percent. However, there are opportunities for intermediate levels of particle removal, called "advanced primary," which are basically enhanced sedimentation processes. The addition of flocculating agents such as polymers, alum, ferric chloride, or lime tend to increase suspended solids removal up to the range of 70 to 80 percent. The cost of advanced primary varies considerably with the coagulating agent used, with polymers being probably the most promising because of the small amount necessary. If too much flocculant is added there may be a large cost for the chemical (e.g., lime) and substantially increased cost of sludge disposal. For ocean discharge it is recommended that additional research be done on developing cost-effective improved sedimentation processes.

One important advantage of advanced primary over full secondary treatment is the fact that polymers (or other chemicals) can be added with minor modifications to existing primary sedimentation tanks at relatively low cost in structures and land. On the other hand, to upgrade a plant to full secondary treatment requires large new batteries of tanks for in-plant aeration and final clarification in addition to the primary sedimentation tanks; the area of tanks is typically doubled.

Another example of how treatment processes and outfall design have been made specific to ocean discharges is disinfection. It has been found with long ocean outfalls, such as off southern California, that there is a trade-off between outfall length and disinfection, while maintaining the same shoreline bacterial count. For example, in Orange County, California, when the Orange County Sanitation Districts stopped using the old 7,000-foot outfall and started operating the new 27,400-foot outfall in 1971, effluent chlorination was completely stopped. Previously, heavy chlorination was necessary over 50 percent of the time to meet shoreline bacteria standards, which are now easily met by natural processes in the ocean. Not only is the saving in chlorine cost very significant, but also the risk of damage to marine ecosystems and in-plant chlorine hazards to personnel have been avoided.

D. Outfalls vs. Treatment Plants--Trade-offs

For effluent discharge into the ocean, the basic choices and trade-offs involve level of treatment and design of the outfall. For the following discussion we will assume that a good program of source control is being implemented, and thus we focus on such pollutants as organic material, nutrients, and pathogens. The performance of an outfall in diluting and dispersing effluent is characterized by the initial plume dilution over the diffuser, possible plume submergence

beneath the pycnocline,* and current patterns. The procedure followed for designing an outfall starts with: (1) data on effluent quantity and quality; (2) environmental data for the ocean; and (3) ambient water quality requirements, and dilution and submergence objectives. The optimum location of the discharge, the diffuser length and depth, and various port details are then determined so that the requirements are met with the desired margin of safety.

By this process, the treatment plant and the outfall are considered as a system with trade-offs. When the treatment is more extensive (e.g., secondary with disinfection), the outfall can discharge closer to shore with less dilution; but on the other hand, when high outfall performance is easily and economically achieved, then less treatment (e.g., primary without disinfection) may be sufficient.

The trade-offs are not simply a matter of cost. When secondary treatment is used (with an implied shorter outfall), there is an additional disposal problem for the increased amounts of digested sludge which may have intangible as well tangible costs. Another factor is that for secondary treatment a long high-dilution outfall may still be desired for ecological reasons, even if it is not essential for bacterial, dissolved oxygen, or turbidity requirements. Since a large fraction of the original nutrients remain in the secondary effluent, high dilutions are helpful for avoiding undue biostimulation.

It is practically impossible to make a generalized economic analysis of the trade-off between outfalls and degree of treatment. It should and must be done on a case-by-case basis. Under the 1972 law, this was not permissible because secondary treatment was mandated regardless of the character of the receiving water or the outfall design; now, with the 1977 amendments, including Section 301(h), such a systems approach is possible because it is recognized that the resulting ambient water quality depends on the outfall design and receiving water characteristics as well as the level of treatment.

Experience suggests that the cost trade-off is sensitive to the mean flow of the system. For small flows, perhaps on the order of one to ten mgd (million gallons per day),** the addition of secondary treatment may be cheaper than building a sufficiently long outfall; on the other hand, for very large systems (several hundred mgd) the cost advantage of a long outfall in deep water over secondary treatment may be very large. The reason for this is that the treatment costs tend to be nearly proportional to the flow rate, whereas outfalls exhibit a much larger economy of scale.

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*The pycnocline is at the water depth where water density changes most rapidly; vertical mixing between the water masses above and below is slow.

**1 mgd = 1.55 ft^3/s = 0.044 m^3/s.

The cost of an ocean outfall depends not only on water quality requirements, but also on the physical hazards and foundation conditions at the site. Factors which will increase outfall costs significantly are: large ocean waves, shifting bottom profiles, poor foundation conditions, earthquake faults, and hard rock and coral which must be excavated. The cost then is very site specific. The depth profile also enters into the cost significantly in the sense that an outfall is most difficult to build through the shallower surf-zone (typically up to 30-foot depth) and easiest to build in the offshore sections, where burial may not even be required (i.e., the pipe may be simply laid on the bottom with rock berms to hold it in place).

To get some idea of cost for purposes of comparison with typical secondary treatment costs we may consider the example of the Sand Island Outfall at Honolulu, Hawaii, which was finished in 1975 (Fischer et al., 1979). The design average flow of that outfall is 164 ft^3/s or 106 mgd, roughly equivalent to the flow from a 100 mgd plant. The length of the outfall (7-foot inside diameter) is 13,500 feet including a 3,384-foot diffuser with a terminal depth of 235 feet. The construction cost was $13.6 million (contract awarded in October 1973); in 1980 prices this would probably have been about twice as much, or $27 million. The construction conditions would be considered somewhat more difficult than average because of about 6,000 feet of coral excavation through the surf-zone. Although the average construction cost would be about $2,000 per foot, the marginal cost of additional length would be much less. A rough cost formula for an outfall for 100 mgd flow might be

$$C = 5,000,000 + 2,500\ Ls + 1,000\ (x - Ls)$$

where

C = cost in dollars;

Ls = length of the surf zone in feet (requiring trestle construction and trenching); and

x = outfall length including diffuser (in feet).

The $5 million constant is the basic fixed cost of mobilization and demobilization. The marginal cost for length is thus estimated to be $1,000 per foot for a seven-foot outfall for 100 mgd for original construction, but not for retrofitting which requires remobilization of heavy equipment.

For a hypothetical example, the required outfall length for primary effluent might be 18,000 feet, but only 12,000 feet for secondary; the surf zone is taken as 4,000 feet. The cost comparisons for two equivalent treatment-outfall combinations are given in Table 1

Table 1

Estimated Typical Cost Differentials of
Outfalls and Treatment Needed for
Primary Versus Secondary Options
(Mean-Flow = 100 mgd)

Treatment: Outfall Length:	PRIMARY 18,000 ft		SECONDARY 12,000 ft		Difference (Sec. - Prim.)	
	Capital	Annual	Capital	Annual	Capital	Annual
			(costs in $ million)			
OUTFALL						
Capital Cost	29		23		-6	
Annual Capital Cost (10.25%, 75 yrs)		3.0		2.4		-0.6
Annual O & M		0.3		0.2		-0.1
Subtotal	29	3.3	23	2.6	-6	-0.7
TREATMENT PLANT						
Capital Cost	41		69		+28	
Annual Capital Cost		5.2		8.8		+3.6
Annual O & M		1.8		4.3		+2.5
Subtotal	41	7.0	69	13.1	+28	+6.1
TOTAL OUTFALL & STP	70	10.3	92	15.7	+22	+5.4

for a design average flow of 100 mgd. Since the capital costs shown are original project costs, the differences understate the cost of projects to upgrade; i.e., if an outfall to 12,000 feet is already built, then the cost to extend it to 18,000 feet would be much more than $6 million because of the mobilization cost; and if a primary plant already exists, the addition of secondary processes would cost more than the $28 million differential shown.

Although the analysis presented in Table 1 is very generalized and ignores site-specific factors, it does show the nature of the cost trade-off between a longer outfall and more treatment (presuming that the ocean currents are favorable for flushing highly diluted primary effluent). The savings in annual outfall costs for secondary effluent versus primary effluent would be only approximately $0.7 million for this case; on the other hand, costs of secondary treatment would represent an increment of $6.1 million for a net increase in cost of $5.4 million annually. This represents about a 50-percent increase over the option of primary plus a longer outfall.

There may be instances where the comparison will be more striking or less striking. The design of the Barber's Point outfall in Honolulu (a new system) considered the effect of the treatment level on outfall design (see R.M. Towill Corporation, 1974). Although the outfall was officially designed for secondary effluent, the design report indicated that the additional length needed for primary effluent was only 600 feet out of a total length of 10,500 feet; and represented only 2 to 3 percent additional cost. Because of the possibility that secondary treatment might not be built in the future, the designers recommended building this slightly longer outfall (i.e., 10,500 feet) to take advantage of the possibility of not being required to go to full secondary. (The mean design flow for this outfall was 59 mgd; the peak design flow, 112 mgd; the depth of discharge, 195-200 feet; the length of diffuser, 1,750 feet, which could have been 1,150 feet for secondary effluent; and the inside outfall diameter was 78 inches.) One of the reasons the marginal length (and cost) is so low here is the bottom topography; the outfall crosses a long coral shelf and then follows a rather steep decline to a depth of about 195 feet where the diffuser turns and follows the 200-foot contour. In order to meet the water quality requirements (especially for nutrients), and take advantage of the favorable density structure to achieve plume submergence, it is necessary to go to approximately 200-foot depth for either primary or secondary levels of treatment.

There are other trade-off possibilities. For instance, consider an outfall which is already built and the choice is between lengthening it and adding secondary treatment. In this case, the cost of the incremental length must include the full cost of mobilization of the construction effort; and if the mean flow is small (on the order of one to ten mgd), then installing secondary treatment might be cheaper. On the other hand, if an agency already has an outfall that performs

very well with primary treatment, then the secondary treatment requirement may have no trade-off in outfall length (because the outfall is already designed to perform for primary effluent).

In the case of combined sewers, the storage, treatment, and outfall disposal are all relatively expensive because of the large flows, especially considering the fact that combined sewer overflows may be a relatively infrequent occurrence (e.g., only 4 percent of the time at San Francisco). Secondary treatment is not the issue here, but rather the question is whether to provide primary treatment for mixed storm-water sewage; or whether to gradually build a system of separate sewers; or whether to do nothing if it is judged that the damage of occasional overflows to coastal waters is less than the cost of correcting the problem. The federal law at present does not clearly specify how storm-water overflows are to be regulated, although the present procedure appears to be to permit it only when a 301(h) waiver is granted (for coastal discharge of less than secondary treated effluent).

E. Sludge Disposal--The Ocean Option

For disposal of digested sludge, the ocean option is precluded by current law, but if it were modified the ocean disposal option would be found in some cases to be much cheaper than land disposal or incineration. As an example, the Orange County Sanitation Districts is faced with a program for dewatering sludge and hauling it by truck inland 30 kilometers to landfills in the foothills of the Santa Ana Mountains on the opposite side of the county from the coastal treatment plant. The regional sludge study (LA/OMA, 1980) has estimated the cost of this disposal method as $75 per ton (raw sludge basis) or $9.7 million per year (1977 dollars), if partial secondary treatment is required (planning Phase II). However, a deep-water sludge outfall to 300-400 meters was suggested as a possible alternate by Jackson et al. (1979), who estimated the cost of a 33,000-foot (10 kilometers) outfall (18 to 24 inches inside diameter) to be between $5 million and $10 million.* The environmental impacts of such a system were predicted to be low, although additional field research and environmental data collection were recommended before any project is built.

* LA/OMA, 1980, estimated that for the year 2000 with full secondary treatment (planning Phase III) the cost of deep-ocean disposal would be $36 per ton (raw sludge basis, 1977 dollars), compared to the landfill disposal cost of $86 per ton for Orange County Sanitation Districts. However, we believe the capital cost estimates used for a marine sludge outfall were much too high.

A comparison between landfill and ocean disposal costs for Orange County Sanitation Districts is presented in Table 2, which includes about $1 million per year for environmental research and monitoring for the ocean option. Although these numbers must be regarded as preliminary (not official estimates), they do indicate the wide difference in annual costs between land and ocean disposal (about $11.9 million vs. $2.75 million). The design capacity is 150 tons of sludge solids (dry weight) per day, consisting of mostly primary sludge anaerobically digested and screened to remove any large particles before discharge. It is assumed that under a Section 301(h) waiver, full secondary treatment will not be required.

Even if an experimental discharge were permitted for only five years, the savings over landfill disposal could still more than pay for an extensive program of ocean monitoring and fully amortize the outfall pipe in five years instead of 30 years. This is an example of a project where an experimental step, if allowed, would be useful, not only for that agency, but also as an opportunity to gain valuable information for further developing the methodology for predicting the transport, fates, and effects of sludge introduced into deep water. Since the risk of such an experiment appears to be very low, such research and demonstration projects are recommended.

The ocean disposal option for sewage sludge, of course, includes barging as well as special sludge outfalls. If barging were permitted in the future, there are various disposal strategies that could be analyzed systematically to predict environmental impacts and to estimate the capital and annual costs. Our ability to predict transport, fates, and effects of barge discharges can also be improved through additional research and monitoring.

The practice of barging is significantly different from sludge outfalls in two respects (Jackson et al., 1979): first, the discharge is near the water surface so that it can have more impact on the photic zone (by reducing light transmission) than a bottom discharge; and secondly, the barges can be programmed to dump sludge at various places, as desired, rather than at a fixed point as for an outfall. Environmentally, the first point is a disadvantage, while the latter is an advantage.

The cost of barge disposal may be more or less than sludge disposal by pipeline depending on circumstances. Larger discharges tend to favor pipelines because continuous pipeline transport is cheaper than batch transport. Higher dilutions and submerged plumes can be more readily achieved. On the other hand, long distances and/or difficult outfall construction conditions favor barge disposal, especially for small or moderate sludge volumes.

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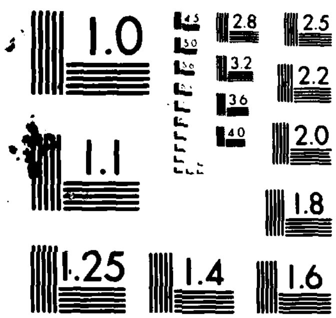

MICROCOPY RESOLUTION TEST CHART
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Table 2

Estimated Alternates Costs of Digested Sludge Disposal for Orange County Sanitation Districts* (150 tons/day)+

	Landfill disposal (by truck)	Ocean disposal (by sludge outfall to 300m depth)
Capital	$ million	$ million
Land	$23-36	
Dewatering, screening	6.0	1.0
Storage	4.5	
Trucking	2.0	
Pipeline		5-10
TOTAL CAPITAL COST	35-48	6-11
Annual Costs		
Capital#	4.0-5.3	0.7-1.2
Annual operation and maintenance	6.6	0.25
SUBTOTAL, Capital and O & M	10.6-11.9	1.0-1.5
Special research and monitoring program	-	0.75-1.25
TOTAL, ALL ANNUAL COSTS ($ million)	10.6-11.9	1.75-2.75
COST PER TON+ (dollars)	$82-92	$13-21

*Based on preliminary data for Phase II from Orange County Sanitation Districts, February, 1981.

#Based on 10.25 percent interest, amortized as follows: Land, interest only; storage tanks and outfall pipe, 30 years; pumping, dewatering and screening equipment, 10 years; trucks, 7 years.

+Actual digested sludge discharge is 150 tons/day which is derived from 350 tons/days of raw sludge. For consistency, unit costs are given in costs per ton of original raw sludge.

In summary, our predictive ability for engineered systems of sludge discharge to the ocean (by pipeline or by barge) has advanced considerably in recent years and will continue to improve as more research is done. For the Southern California Bight, Jackson et al. (1979) developed various predictive models and applied them to analyze the environmental impacts of various alternative methods of sludge disposal in deep water. For this area they recommend outfall pipelines to about 1,000-foot depth as the best new method for further engineering evaluation. Additional research needs were also identified.

F. Monitoring

An important part of the ocean option for disposal of sewage or sludge (when permitted) is an adequate monitoring program to identify any trends in environmental effects or to discover any new problems. Monitoring is typically required of the discharge agency by the regulatory agency. The discharger either does its own monitoring or else contracts the work out, and reports to the regulatory body.

There are basically two kinds of monitoring: (1) measurements of the chemical quality of the effluent and the flow rate, and (2) measurements of ambient water quality in the vicinity of the discharge and along the nearby shoreline. For large discharges the required monitoring stations may be scattered over 10 kilometers in each direction.

The main purpose of monitoring efforts, it appears, is to determine compliance with regulations rather than for research. For example, measurement of numerous water quality parameters may be required once a week (or more often), but no current data, density profiles, or other information is required even though it might be useful to understanding synoptic conditions at the time the water quality samples are taken. If a discharge is found to be out of compliance at a particular time of sampling, there is nothing that can be done in "real time" (because the offending plumes have already been discharged into the ocean). The fastest response is to start or stop chlorination, or adjust the dose of chlorine, or any other chemical that may be added as part of the treatment process (such as polymers to enhance sedimentation).

Unpermitted doses of toxic pollutants cannot be quickly detected in the effluent nor can the source of them be readily found without extensive investigations. Therefore, it appears that too much money and effort is spent on routine monitoring which could be better spent on research-oriented tasks and looking for new problems. This point is well illustrated by the industrial discharge of waste DDT (until 1970) through the sewer system of the Los Angeles County Sanitation Districts and the outfalls off Palos Verdes. The extensive adverse

effects of this discharge were not uncovered by routine monitoring (DDT was not on the list of regulated substances then), but rather it was found through a special series of measurements and studies stimulated by the publication of research findings linking nesting problems of marine birds to bioaccumulation of DDT in the marine food chain.

The discharges of toxic pollutants from municipal sewer systems are very unlikely to accumulate to acutely toxic levels. The question is whether existing levels may be chronically toxic. Thus, the best strategy for monitoring the environment is to use tests which are integrative in nature, such as measuring at regular intervals (like a year) the accumulations of trace contaminants in bottom sediments, or in particular indicator shellfish at designated locations (Goldberg's "mussel watch"). Such long-term monitoring will be required of any discharger who gets a Section 301(h) waiver.

However, the control of short-term problems, such as infection by pathogens, must be measured by instantaneous point samples of receiving water at some regular short interval depending on the size of the discharge, the intensity of beach use, and the rapidity with which prevailing currents or stratification may change. Measurement intervals are typically in the range of daily to weekly.

The cost of monitoring programs is difficult to determine. However, a good indication is given by an analysis by the EPA of the cost of providing the necessary information and monitoring in the discussion of the proposed ocean discharge criteria (45 Federal Register 9548). For a large POTW discharging 360 mgd, the incremental user charge is estimated to be only $0.06 per month; however, that would rise to $0.80 per month for POTWs of 5 mgd capacity and to just over $3.00 per month for plants of 0.5 to 1 mgd. The sharply rising unit costs per user as the plant size decreases indicates that monitoring cost is a variable which decreases much more slowly than the discharge. For small discharges especially, it is highly doubtful that the value of the information obtained is commensurate with the costs incurred, simply because small discharges to the ocean represent very small threats in most cases.

In the past, the design of monitoring programs has included an excess of routine measurements, but insufficient research aimed at identifying new relationships or problems. A notable example of a forward-looking monitoring and research effort was the establishment of the Southern California Coastal Water Research Project (SCCWRP) in 1969, by the County Sanitation Districts of Los Angeles and Orange Counties, the cities of San Diego and Los Angeles, and Ventura County. Organizationally it is separate from the sewage agencies and under an independent board. The scientific work is guided by a director and a special board of consultants. Although the funding has come primarily from the discharge agencies, additional support has come in recent

years from various other research funding agencies. SCCWRP issues comprehensive biennial reports summarizing results of numerous special studies (see SCCWRP, 1979-80, for the latest report), and occasional special publications, as well as publishing papers in the technical literature.

The agencies which founded SCCWRP discharge about 1 billion gallons per day of effluent to the Southern California Bight. Although they maintain their own routine monitoring effort involving frequent sampling of the shoreline and offshore waters for compliance with the requirements, they wisely established the special organization to conduct ongoing and long-term special studies of the effects. Some of the best results in the literature come from this effort. The costs of such research efforts, in the total context of wastewater disposal costs, are small and well worthwhile.

G. Summary of Management Alternatives

A well-designed program of disposal of municipal waste water and sludge to the ocean, as we have seen, includes a mixture of source control, sewage treatment and sludge processing, appropriate outfalls (or barging operations), and monitoring and research efforts commensurate with the scale of the discharge and the risks. The level of activity in each category is clearly related to each of the others, and the engineer-manager should seek an optimum combination of efforts. For example, good monitoring measurements of the accumulation of metals in sediments or in the food chain will provide the basis for rational discussions on how much source control effort is needed for particular substances. With monitoring and research information we can focus the attention on substances which are believed to be most important in the environment and avoid excessive efforts on nonproblems.

Overlying all of the foregoing should be a program of geographically varying "management standards"; i.e., requirements for waste management which are set on a regional or case-by-case basis in sensible time steps, with the flexibility to adjust each control program in response to the ocean observations of the effects of a particular discharge. The compliance schedule would allow enough time and flexibility to study the effects of different actions as the basis for any further tightening of the requirements. It is not necessary, nor economically efficient, to tighten the requirements in one step to the most demanding level that might possibly be necessary, because in most instances we are not dealing with a water quality crisis but rather with some long-range concerns. The ability to make wise and cost-effective decisions is greatly improved by having time for feedback loops.

Another reason for using management standards is to achieve better integration of marine disposal options with air and land disposal. For example, time could be provided for incremental implementation of alternative disposal systems to land or air. Thus, if it is believed that it is better to dispose of sludge on land rather than to the ocean, it might be wise to establish such an operation for a minor fraction of the sludge (such as 10 percent) to fully investigate the feasibility and environmental effects of the alternate disposal procedure before making a full-blown commitment to switch.

Heretofore, federal legislation and regulations have not permitted enough flexibility in management alternatives. The rigidity of the regulations does not encourage innovation in developing new cost-effective measures. Government policy so far has been relatively unresponsive to new technological approaches or to new environmental research results because of the lack of flexibility or regionalization of the regulations.

POLICY ALTERNATIVES AND ADMINISTRATION

The previous section gave an overview of the key technical components of management alternatives which could improve ocean disposal practices for municipal waste water. This section treats general policy elements of a sensible strategy.

A. Balancing the Effects and Risks of Ocean Discharge Against the Costs of Avoidance

It is an obvious proposition that discharge of pollutants into the nation's waters imposes costs--whether through adverse effects on humans and their environment, or through the threat of such effects. It is an equally obvious proposition that avoiding these costs can itself be very expensive. The need for trade-offs, for weighing one category of costs against the other with an eye to achieving a reasonable balance, is quite clearly posed. Yet, by and large, present federal policy disdains such a balancing approach. Put differently, present policy reflects a very conservative (in the sense of risk-averse) attitude: high (and costly) levels of control are required, without much regard to resulting benefits. Put still differently, the benefits of demanding controls are presumed to be very large.

A conservative approach is not by any means a necessarily bad approach. Quite to the contrary, for example, it seems clearly justified in the case of toxic pollutants. Whether it is justified with regard to disposal of more conventional pollutants into ocean waters is, insofar as this volume is concerned, an open question. It is clear

to us, however, that in the limited instance of ocean disposal of conventional municipal wastes, the conservatism of present policy--a general (minimum) requirement of secondary treatment for POTW effluent --is, on balance, unwarranted.

Several considerations support this conclusion. First, a requirement of secondary treatment for POTWs discharging into ocean waters entails very substantial costs--not just direct capital, operating, and maintenance costs, but also, for example, increased costs of sludge disposal. Second, alternative technologies--much less expensive than secondary treatment, but satisfactory because they take advantage of the oceans' enormous assimilative capacities--exist and are in fact in use. Third, and assuming effective source-control programs, secondary treatment, for all its costs, may yield negligible benefits. Conventional POTW pollutants, e.g., BOD and suspended solids, simply do not pose large risks for ocean waters when subjected to primary treatment and discharged by well-designed means. Even cautious calculations, then, suggest the wisdom of a more balanced approach in the case of ocean waters.

Congress, it appears, endorsed this conclusion in the Clean Water Act of 1977. Section 301(h) of that legislation provides for modifications of secondary treatment requirements in the case of some ocean discharges. While the modification provisions are welcome, they are not without shortcomings. They apply only to existing discharges, only for a limited time, and (probably) only to limited coastal regions; they *cannot* result in imposition of additional controls on other sources; they are rigidly constrained by water quality standards; they entail difficult, expensive, and time-consuming application procedures (the possible adverse effects of secondary treatment have never received the scrutiny to which proposed modifications are subjected). All in all, it is too early to tell whether Section 301(h) will reflect the balanced attention to costs and benefits so important to sound ocean discharge policy. It is clear, though, that the section does neglect a second important policy component, considered next.

B. Relating Ocean Discharge Policy to Other Disposal Options

1. Alternatives to Ocean Discharge

Federal law for ocean discharge is written with the underlying premise that land disposal of effluent and sludge may often be environmentally superior to ocean discharge. For example, the Ocean Dumping Act, by virtue of the ban on ocean dumping after 1981, presumes *a priori* that land disposal must be better than ocean disposal for digested sludge and other solid wastes. The multi-media choices and trade-offs for sewage sludge disposal have been discussed in detail in a publication of the National Academy of Sciences. (See bibliography reference 6.)

Since the basic laws were formulated in the early 1970s, there has been greatly increased awareness and measurement of groundwater contamination by toxic pollutants. There are apparently greater risks than heretofore realized for contamination of groundwater by surface disposal of both solid and liquid wastes, followed by rainfall percolation and leaching of contaminants to the groundwater supplies. Because groundwater is a major source of drinking water, the direct public health risks of land disposal for a given effluent with trace contaminants (and nitrates) are generally much greater than for marine disposal. Not only does the ocean provide much greater dilution (on the order of several hundred to one for a good outfall), but also the ocean is not a source of drinking water.

The groundwater example illustrates an obvious but often overlooked point. Decisions involving waste discharge into the ocean must compare the costs and risks of ocean disposal with those of other methods of disposal. If we had only to minimize the impact on the ocean without regard to any other environmental media, then the answer would be very simple: zero discharge to the ocean. Do anything else with the waste water at any cost but do not put any of it into the ocean! Plainly, though, such an attitude is unrealistic. As long as people choose to live in urban areas along the seacoast, there is no way to avoid some impacts on the quality of coastal waters not only from sewage, but also from storm-water overflows, street runoff, aerial fallout, ship pollution, and so on. Only in rare instances will land disposal be a viable alternative to ocean disposal. Factors favoring land disposal might include an arid climate with a high evaporation rate, a big demand for reclaimed water, abundant land, the location of land disposal sites at places where there is no groundwater threat, small wastewater flows, and unfavorable oceanographic conditions for an outfall. In addition, if the source of the waste water becomes a significant distance inland from the coast, then land or stream disposal becomes relatively more attractive because of the conveyance cost to the ocean. At the present, one of the longest transit distances for municipal sewerage systems from origin to ocean discharge is about 100 kilometers (e.g., Los Angeles County Sanitation Districts system).

2. Policy

Efforts to protect ocean waters without regard to effects on other resources--land and air--could well result in net social losses. Constraints limiting waste disposal on land or in the air, without regard to their implications for ocean disposal policy, could quite easily yield a situation where all disposal options have been made infeasible. Even with programs to limit the production of wastes and to promote recycling, there will still be residuals which must go somewhere, and the only alternatives are air, land, and water, or some mix of these receiving media.

In light of these considerations, it is evident that a sound approach would: (1) promote feasible source control, including

reduction in waste production, pretreatment, conservation, and reuse; (2) direct disposal of remaining residuals, under proper controls, to those media that can best tolerate them. The effort, in short, should be to minimize the sum of all relevant costs, taking all media into account.

As sensible as such an approach is, it does not represent present policy. Quite to the contrary, the present approach constrains disposal from all sides, and without much regard to the interrelated effects of doing so. In our particular case, ocean disposal of municipal waste, matters are in fact worse than this. Chief reliance on secondary treatment results in increased sludge production, yet opportunities for sludge disposal are severely limited. Section 301(h) modifications can have a positive effect here, but an unduly narrow one. Modification procedures should include a searching analysis of alternative disposal options, but it appears they do not. The impact on ocean waters of granting a modification is considered with great care; the impact on land and air of denying a modification is virtually ignored. Thus, for example, the limited assimilative capacity of some ocean waters of the East Coast is a matter of major concern, while similarly limited air and land capacity are more or less overlooked.

In short, federal controls are far less integrated than they should be and could be; a more systematic approach is both necessary and possible. This is not to say that trade-offs must be made with fine-tuned precision--more rough-and-ready calculations would be a satisfactory beginning. Nor should our comments suggest an instant need for a completely integrated approach to environmental management. Rather we recommend a more modest program, limited to ocean disposal of municipal waste and sensitive simply to the most obvious trade-offs among air, land, and water as disposal sites. Given a relatively small number of sources and a relatively good understanding of the options and constraints they face, such a more integrated approach to the municipal waste-ocean disposal problem would appear to be manageable.

C. Approaching Policy on a Regional Basis

If the interrelated effects--costs and benefits--of alternative management strategies are to be considered in formulating controls on ocean discharge of municipal waste, then this means almost necessarily that policy must be developed on a regional not a national basis. Land, air, and water resources differ significantly from place to place, and controls that make sense for one area will not suit another. Ocean waters are regionally variable, for example--some provide greater assimilative capacity than others, some have more sensitive ecosystems than others, some are subjected to more effluent input than others. Variations like these should be taken into account; standards and controls should be regional. Section 301(h) adopts such an approach

in part by taking careful account of differences among ocean waters. As mentioned above, however, the modification provisions tend to ignore areal differences among air and land resources; the tendency is a product of the unsystematic approach of present environmental controls. In other words, the need for the ocean disposal option (as for sludge) depends heavily on the impacts of not using the ocean, which may vary considerably among regions.

Developing policy on a regional basis implies not only different controls for different areas, but also different timetables as well. For example, a phase-out of ocean dumping by a specified date may well prove to be appropriate for one set of cases in one region, but a different set may need a different schedule.

Present environmental policy in general displays undue amounts of national uniformity, and the job of revamping existing controls in order to take account of regional variability will be a big one. But that is not the concern here. Ocean disposal of municipal waste presents a discrete set of problems and can be dealt with accordingly, without having to address larger reforms.

D. Adjusting Policy in Response to New Information

Another important aspect of ocean discharge policy should be flexibility to respond to new information of all kinds: research on transport, fates, and effects of pollutants in coastal waters; monitoring results near outfalls; technological advances (in all aspects of source control, treatment plants, and outfall construction); impacts on other media related to ocean discharge policies; and changing costs (both capital and O&M). Many present requirements are so rigidly prescribed (in legislation or regulations) that changes may take years to get through the "system". Individual POTWs can respond with more innovation and pollution control for the money if regulatory agencies have enough flexibility to adjust standards on a timely case-by-case basis. (See also the discussion of management standards in Section G above.)

Sewerage agencies should also be encouraged and supported to undertake research and demonstration projects to improve overall environmental management. A good example is the use of deepwater special outfalls for sludge disposal off Southern California as suggested by Jackson et al. (1979). However, current policy prohibits such a project, probably even as a research and development activity. With good source control of contaminants such a project would not be risky on a trial basis to observe the impacts.

Without flexibility, we deny ourselves the opportunity to profit by our experience--both good and bad.

SUMMARY AND CONCLUSIONS

Much has been learned from our experiences with disposal of municipal sewage effluents and sludges in the ocean, and ocean discharge policies can be significantly improved to make the best use of this scientific and technological knowledge. In brief, our main conclusions are as follows:.

The coastal ocean has significant capacity for assimilation of municipal wastewater (both treatment plant effluents and digested sludge). The effects of ocean discharges vary widely depending on the design of the outfall, the quality of the effluent, and the characteristics of the receiving waters.

Present law does not allow enough flexibility to apply the most cost-effective approaches to pollution control on a case-by-case or regional basis. However, a recent reversal of this trend is found in section 301(h) of the Federal Water Pollution Control Act Amendments of 1977, which allows applications for exceptions from mandatory secondary treatment.

Present policy does not provide for integrated regulation of oceans, fresh waters, land, and air, in spite of the fact that stricter ocean standards generally lead to increased impacts on other media.

The prohibition of sludge dumping in the ocean is a policy which is not based on scientific, engineering, and economic evaluations of trade-offs, considering alternative disposal methods impacting the land, fresh waters, and/or atmosphere.

In general, the highest priority is for better control over the releases of trace toxic chemicals and heavy metals to the ocean (as well as to other environmental media). The only viable strategy is control at the industrial sources to prevent release into the sewers.

Sewage treatment processes required for ocean discharge should be more specifically directed at ocean water quality problems. When effluents are well diluted by well-situated, high-dilution outfalls, there is little value in removal of BOD (biochemical oxygen demand) by secondary treatment (or decrease in nutrients by tertiary treatment). However, improved removal of particles by advanced primary sedimentation is directly beneficial to ocean-water quality in many cases, and is much cheaper than full secondary treatment.

Outfall technology has advanced considerably in recent decades with the use of longer outfalls with multiport diffusers. The initial dilutions and subsequent dispersion of the plumes can be

predicted with good reliability. Long, high-dilution outfalls reduce the need for secondary treatment and disinfection, and may be economically attractive alternatives to secondary treatment when the ocean conditions are favorable.

Sludge disposal methods in the ocean can be improved. Instead of being banned outright, the ocean sludge disposal option should be kept open for analysis and evaluation on scientific, technical, and economic grounds just as for other options. In some regions where the ocean has good assimilative characteristics, but air and land resources are already overstressed, the ocean disposal option may be the most desirable (such a region may be the Southern California coast).

Research and demonstration projects should be encouraged to gain more information on effective techniques for management of ocean disposal. An example would be the deep-water (300 meter) disposal of sewage sludge off Orange County (see Section E above) for a trial period of five years to observe transport, fates, and effects of the sludge particles, and to improve the methodology for analysis of such discharges in general.

Monitoring programs for ocean water near outfalls should be designed for early detection of any new problems as well as for routine enforcement of regulations. Because of the high cost of many monitoring programs, more research is needed on optimal monitoring strategies.

The basic elements of good policy for ocean discharge are:

(a) costs of control which are commensurate with environmental benefits;

(b) integration with policies for other media;

(c) flexibility to account for wide variations in the nature of coastal waters; and

(d) flexibility to adjust control programs on an incremental basis in response to environmental monitoring results or new scientific information.

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